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# EFFECTS OF THE COOLING SYSTEM PARAMETERS ON HEAT TRANSFER AND PERFORMANCE OF THE PAFC STACK DURING TRANSIENT OPERATION

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EFFECTS OF THE COOLING SYSTEM PARAMETERS ON HEAT TRANSFER AND PERFORMANCE OF THE PAFC STACK DURING TRANSIENT OPERATION

RABI M. J. RIDHA

ABSTRACT

An experimental investigation for the effects of transient operation of a phosphoric acid fuel-cell stack on heat transfer and temperature distribution in the electrodes has been conducted.

The proposed work utilized the experimental setup with modifications, which was designed and constructed under NASA Contract No. NCC-3-17(5). The experimental results obtained from this investigation and the mathematical model obtained under NASA Contract No. NCC3-17(4) after modifications, were utilized to develop mathematical models for transient heat transfer coefficient and temperature distribution in the electrode and to evaluate the performance of the cooling system under unsteady state conditions. The empirical formulas developed were then implemented to modifying the developed computer code.

Two incompressible coolants were used to study experimentally the effect of the thermophysical properties of the coolants on the transient heat transfer coefficient and the thermal contact resistance during start-up and shut-down processes. Coolant mass flow rates were verified from 16 to 88.2 Kg/hr during the transient process when the electrical

power supply was gradually increased or decreased in the range (0 to 3000 $W/m^2$). The effect of the thermal contact resistance with a range of stack pressure from 0 to 3500 KPa was studied.

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## LIST OF SYMBOLS

$A$ = Area

$C_p$ = Heat Capacity

$D$ = Diameter

$E$ = Voltage

E.E. = Electrical energy rate per unit area

$h$ = Heat transfer coefficient

$K$ = Thermal conductivity

$K_c$ = Cooling fluid thermal conductivity

$\dot{m}$ = Mass flow rate

$Q$ = Heat transfer rate

$Q/A$ = Heat flux

$\lambda$ = Constant

$\theta$ = Constant

$t$ = time

$\Delta T$ = Temperature differential

$T_w$ = Wall temperature

$T_\infty$ = Fluid temperature

$\frac{dT}{dx}$ = Temperature gradient

$r$ = Thermal contact resistance, unless otherwise specified

$T$ = Temperature

$\rho$ = Density

$Pr$ = Prandlt number

$Re$ = Reynolds number

$\bar{V}$ = Overall heat transfer coefficient neglecting the thermal contact resistance

$v$ = Velocity

$\dot{V}$ = Volumetric flow rate

ox = Length of element

$\eta$ = Dynamic viscosity

$\gamma$ = Kinematic viscosity

$U$ = Overall heat transfer coefficient

$u$ = Internal energy

$\alpha$ = Stack pressure constant

$\lambda$ = Time constant

$\partial$ = Flow constant

$X$ = x-coordinate

$Y$ = y-coordinate

$P$ = Pressure

$Nu$ = Nusselt number

$\Delta x$ = Conduction thickness

# CHAPTER I

# INTRODUCTION

A phosphoric acid fuel cell power plant is an energy conversion system that can efficiently utilize different hydrogen rich fossil fuels, reduce emission of harmful chemicals, and offer a very economical co-generation system. Therefore, fuel cell system analysis efforts concerned with different systems design and operational criteria are essential for design optimization to improve system performance and cost effectiveness.

## 1.1 Fuel Cells

A fuel cell is defined as an electrochemical device which can continuously convert the chemical energy of hydrogen fuels and oxidant to electrical energy. Most of the available fuel cells today are primary electrochemical cells, and generate electrical energy in a similar way as the conventional primary cells, such as the very commonly used zinc-manganese dioxide battery. However it should be noticed that the process of galvanic oxidation that actually causes the production of electrical energy in fuel cells and, which resembles the process that produces energy in conventional primary storage batteries, is continuous. That is, mainly due to the fact that the construction of fuel cells permits continuous feed of reactants and continuous

product removal during the irreversible electrochemical oxidation process. Therefore, different design and engineering from that found in the conventional primary storage batteries are required in the case of fuel cells because of that continuous operation. In addition, the fuel cell chemical reactions always involve chemisorption and catalytic processes.

Basically the phosphoric-acid fuel cell system consists of two electrodes, cathode (positive electrode) and anode (negative electrode), separated by an electrolyte. The electrolyte will serve as a medium to transmit ions. Hydrogen, the fuel, is supplied to the anode while oxygen, the oxidant from air, is supplied to the cathode. Utilizing a catalyst on the anode causes the disassociation of the hydrogen molecules ($H_2$) into hydrogen ions and electrons. Then the hydrogen ions travel through the electrolyte to the cathode and react with electrons supplied by an external circuit load. The hydrogen atoms react with oxygen to form water. This process can be summarized for a $H_2$-$O_2$ fuel cell as follows (see Figure 1).

A. Anode Reaction:

$$H_2 \rightarrow 2H^+ + 2e-$$

B. Cathode Reaction:

$$1/2\ O_2 + 2H_2^+ + 2e- \rightarrow H_2O$$

C. The Control Volume Reaction:

$$H_2 + 1/2\ O_2 \rightarrow H_2O + Q + E.E.$$

where:

$Q$ = thermal energy,

E.E. = electrical energy.

The anode reaction and the cathode reaction proceeds until a potential is established. This will bring the reaction into the equilibrium exhibited by the control volume reaction equation. Figure 2 shows the potential relations of a complete fuel cell. In general, the cell potential can be defined as:

$$\Delta E = E_{cathode} - E_{anode}$$

## 1.2 Fuel Cell Classification and Advantages of PAFC

There are several methods of classifying fuel cells, mainly according to their components and structure. An important classification of fuel cells is according to the used electrolyte. Essentially there are three types of fuel cells being developed to be a complete or a co-generation power plant; acid (A), molton carbonate (MC), and solid oxide fuel cells. These fuel cells are further distinguished by the temperature of operation classification.

Acid fuel cells utilize acid electrolytes because acids are tolerant to carbon dioxide which permits the use of hydrogen and oxygen with low purity. Phosphoric acid fuel cells are the most developed fuel cells, according to reference [1]. In addition, PFAC is economical to build and operate due to its simple design, (see Figure 3).

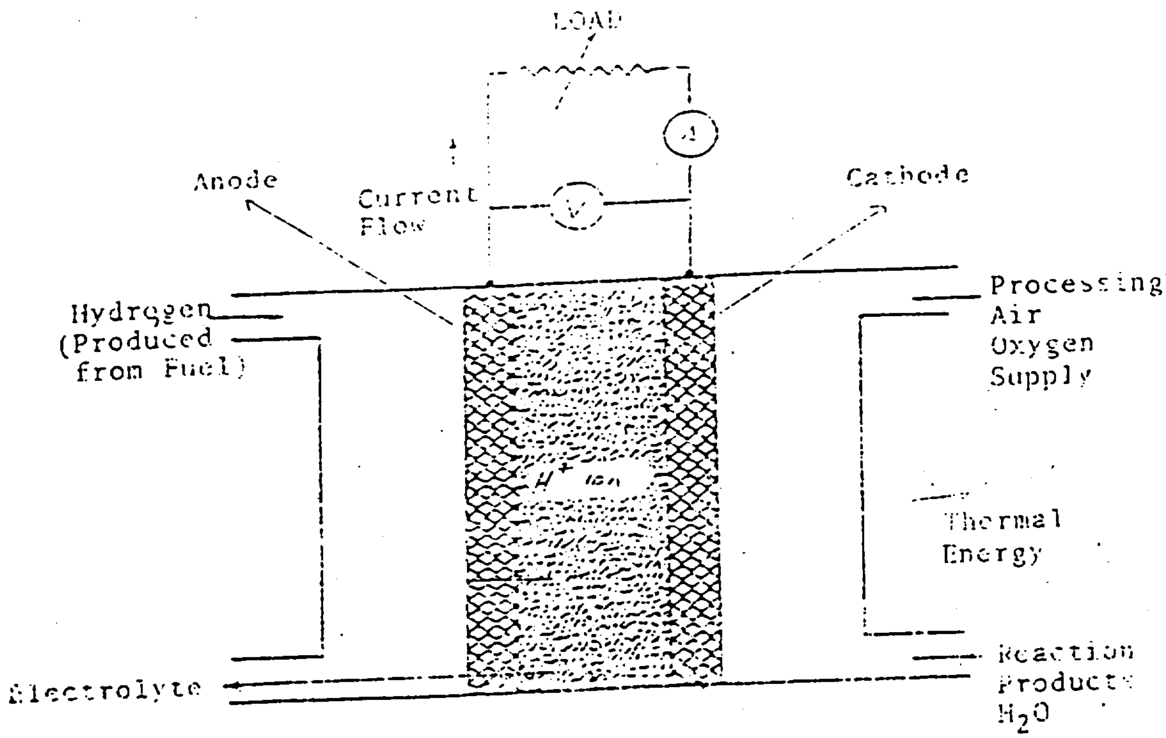



Figure 1. The Fuel Cell Concept.

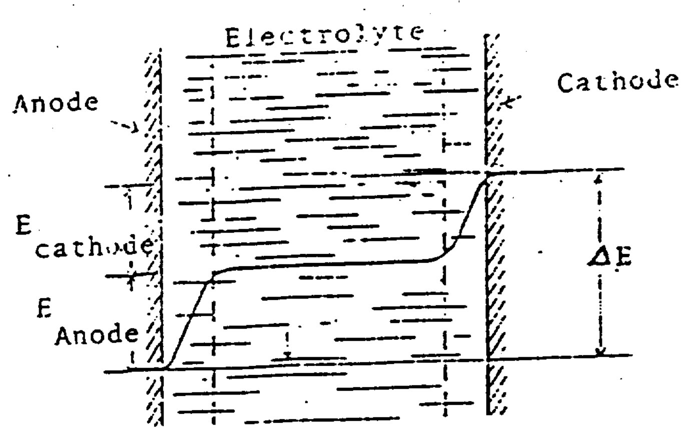



Figure 2. Potential of Fuel Cell

### 1.3 PAFC Systems

Figure 4 shows a diagram of a simple phosphoric acid fuel cell power plant. The plant consists of three major subsystems:

1.3.1 Fuel Processor: This subsystem consists of three components. The reformer which is a catalytic reactor with variable temperature that can reach 1200°C with a pressure of 10 atm. Double shift converters and heat exchangers will function in association with the reformer to consume fossil fuel such as natural gas, methanol and naphatha to produce hydrogen.

1.3.2 Fuel Cell Power Subsystem: Through this stage the Oxygen-Hydrogen reaction takes place and electrical energy, thermal energy and water will be the reaction products. The thermal energy generated is removed continuously by a cooling system to avoid the accumulation of heat which can cause high thermal stresses and electrode plate failures. This subsystem basically consists of several fuel-cell stacks. Cooling is provided to these models by arranging them in a sandwich configuration where the cooling plates surrounds a group

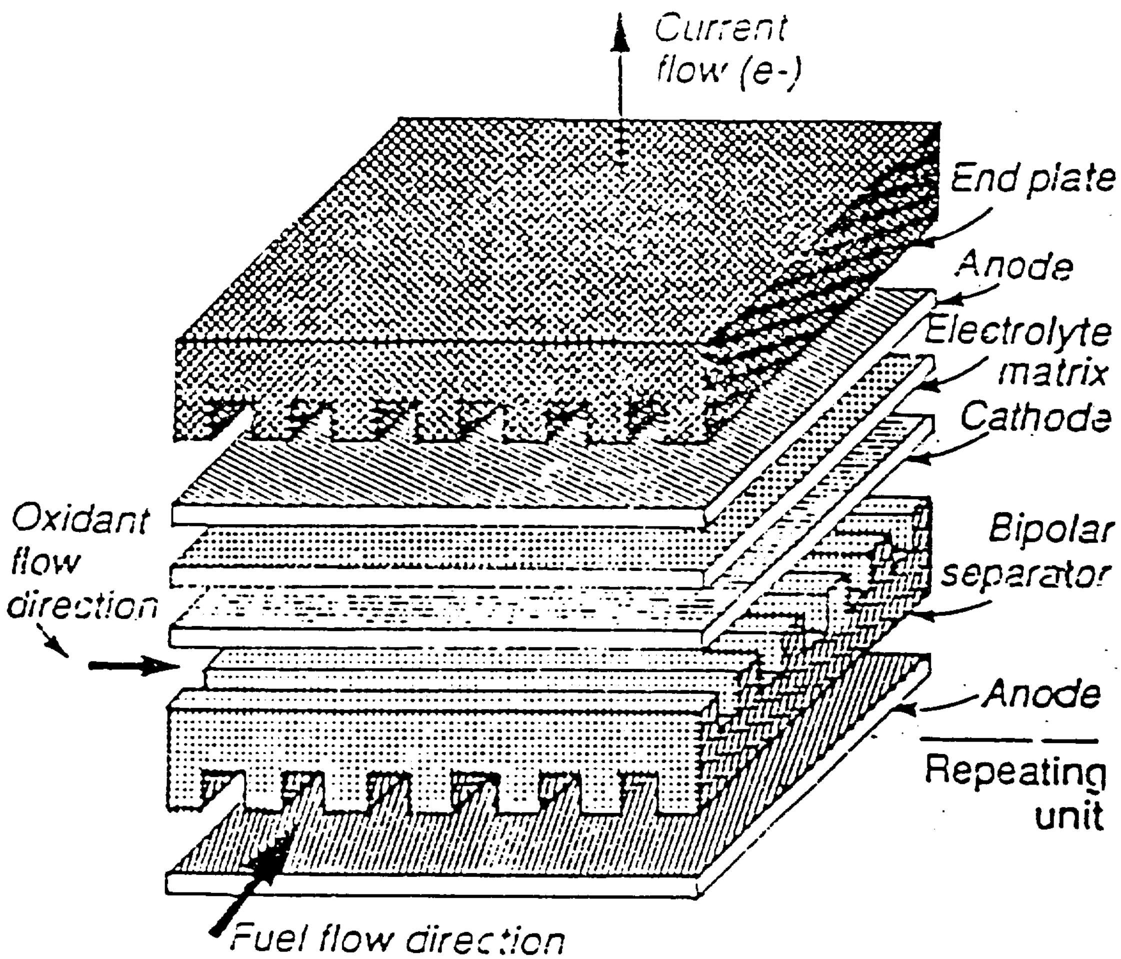



Figure 3. Principal of Operation of Fuel Cells in General. [Reference 16]

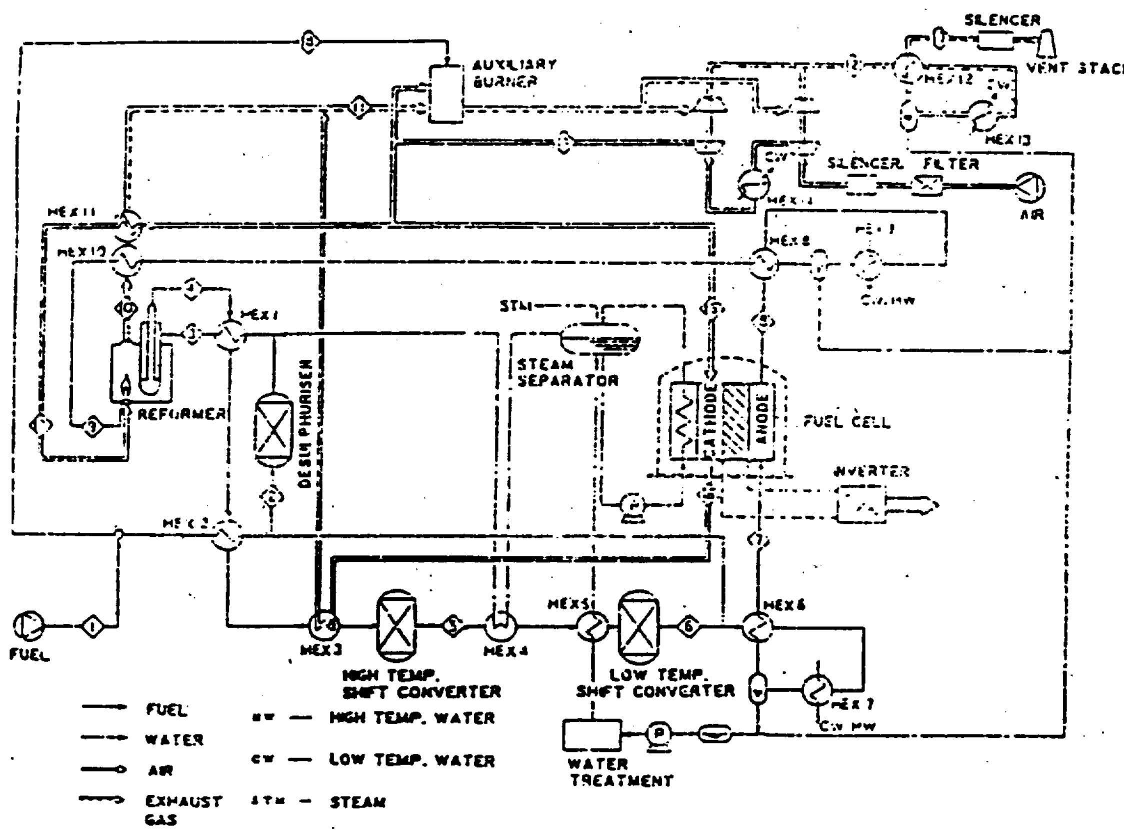



Figure 4. Process-Flow Chart for a (PAFC) Power Plant. [Reference 12]

than 8 hours. Plant control during COLD STARTUP will be manual.

### 1.4.2 WARM STARTUP

WARM STARTUP transient mode is defined as the plant transient from STANDBY to POWER. The plant will be designed for WARM STARTUP to the minimum POWER condition in a time interval of less than one hour. Plant control during WARM STARTUP will be either automatic or manual.

### 1.4.3 WARM SHUTDOWN

WARM SHUTDOWN transient mode is defined as the plant transient from POWER to STANDBY. The plant will be designed to complete a WARM SHUTDOWN from minimum power in a time interval of less than one hour. Plant control during WARM SHUTDOWN will be either automatic or manual.

### 1.4.4 COLD SHUTDOWN

COLD SHUTDOWN transient mode is defined as the plant transient from STANDBY to COLD STOP. The plant will be designed to complete a COLD SHUTDOWN in a time interval of less than 8 hours. Plant control during COLD SHUTDOWN will be manual only.

### 1.4.5 EMERGENCY SHUTDOWN

EMERGENCY SHUTDOWN transient mode is defined as the plant transient from a faulted condition during power operation to STANDBY. The plant will be designed to complete an EMERGENCY SHUTDOWN in a time interval of less

than 1.5 hours; however, plant electrical power output will be disconnected from the utility transmission line in nearly 0.05 seconds. Plant control during EMERGENCY SHUTDOWN will be automatic only.

### 1.4.6 EMERGENCY STOP

EMERGENCY STOP is defined as the plant transient from a faulted condition during any plant operation or transient to COLD STOP. Plant control during EMERGENCY STOP will be automatic only.

The NASA Lewis Research Center, Fuel Cell Office,as the lead center for the PFAC Technology Program, has directed research and development efforts toward reducing cost, increasing life span, and improving performance and reliability of the fuel cell stack. In the technology area, some of the difficult problems that prevent the attainment of these goals are caused either by high temperatures at some regions of the electrode plate surface or by excessive temperature difference. While high temperature can cause corrosion of various components in the fuel cell module and excessive boiling and evaporation of the electrolyte, high temperature difference between various regions can produce thermal stresses that result in cracking or warping of the cathode and anode plates. These material problems can be especially compounded when the fuel-cell stack is subjected to sudden or gradual change of the electric output which is usually accompanied by a proportional change in the rate of

flow of the heat generated. As a consequence, the fuel-cell module undergoes a finite volumetric expansion or reduction, depending on the change in the rate of heat generated. In turn, an increase or decrease of the volume of the stack will produce a proportional change in the clamping pressure which is used to hold the stack of fuel-cells and cooling plates together. However, the investigations, which were conducted under NASA Grant No. NCC 3-17(5) proved that a strong nonlinear functional relation exists between the clamped pressure and the overall heat transfer coefficient between the coolant and the electrode plates.

Thus, in addition to maintaining an almost uniform temperature on the electrode plates under steady state condition, the cooling system must make the necessary adjustments to cope with the compounded problem of changing the overall heat transfer coefficients and the rate of heat flow under unsteady state conditions. To achieve these tasks, accurate information concerning the nature of the functional relation between the stack clamped pressure and the overall heat transfer coefficient and the temperature distribution in the electrode plates, under unsteady state conditions, will be needed.

It should be noticed that previous work, under NASA Contract No. NCC 3-17(4), was directed to develop a computer model for the transient temperature distribution in the electrode plates and the fuel-cell stack. However, this

contains various heat transfer coefficients that have not been experimentally determined and, thus, have not taken into consideration the effect of the thermal contact resistance which effect the performance of the (PAFC) performance dramatically.

# CHAPTER II

## LITERATURE REVIEW

Only limited information exists on phosphoric acid fuel cell temperature distribution, stack pressure effects, thermal stability and cooling requirement during transient operational conditions. Alkasab and Lu [1] studied the response of a phosphoric acid fuel-cell stack power plant. They developed a mathematical model to describe the mass and heat transfer rates. A Fortran computer code was developed utilizing the mathematical model to simulate the effect of the current density, cell-plate dimensions, and reactant flow rates, on the temperature distribution. Baker, et. al. [2,3] conducted intensive studies of electrochemical systems. A mathematical method was developed for both thick and thin stacks. The peak stack temperature was estimated for an isothermal wall case. Green's function was used to develop a formula to detect the non-uniformity of heat generation. Westinghouse [4,5] developed a simulation code which uses finite element analysis to calculate current-voltage characteristics, thermal energy generated and power as a function of the reactants' properties and the fuel-cell temperature distribution. Alkasab [6] et. al. investigated the performance of the PAFC model and succeeded in developing a thermodynamics model. Boyle [7] analyzed the

heat transfer characteristics of the turbulent flow through serpentine passages. Buggy [8] conducted a feasibility study of using fuel-cells as commercial electric utilities. NASA [9,10] was heavily involved in several important researches concerning the performance of experimental PAFC under different transient operational conditions. In those studies, the efficiency of the cooling system was tested when separate gas, process gas and liquid cooling fluid are used. NASA [11] presented a comparison that considered the effect of different cooling systems on the performance, construction simplicity, reliability, thermal pollution, and cost of cooling subsystem and electrolyte cost. Two phase inter-cell cooling was tested by U.T.C. [12] for PAFC. The testing revealed the poor performance of that cooling system due to the need to protect the copper tubes in the corrosive acid environment which lead to dramatically reducing the convective and conductive heat transfer rates. Alkasab and Abdul-Aziz [13] conducted an experimental and analytical study of the effects of the cooling system perameters on the electrode heat transfer characteristics and investigated the stack pressure effect on the heat transferred by the coolant, the thermal efficiency, the thermal contact resistance and the effective temperature differential. The study revealed the dependence of the overall heat transfer coefficient and the thermal efficiency on the stack pressure for the different coolants and cooling system configuration used. Significant improvement in both

the overall heat transfer coefficient and the thermal efficiency were noticed with higher stack pressure. Abelson [14] monitored the transient performance of a 200 kw PAFC plant and noticed that the equipment can respond rapidly to changes in the loads and efficiency is approximately constant as a function of demand in the interval 30% to 100% of the rated capacity.

Conway [15] considered PAFC researches in Europe and summarized the development achieved so far. The study concluded that PAFC as a co-generation system can be considered reliable for transient loading. Makansi [16] studied the feasibility of the concept of integrating power systems utilizing PAFC systems and PAFC units for residential applications. The results reported by the study predicts a steep decrease in the PAFC construction and operational costs of PAFC as a co-generation system using natural gas as a fuel. A time-dependent performance analysis of a 200 KW PAFC field test system at Hotel Plaza Oraka, Japan was presented by Singer et. al [12]. High efficiencies were noticed when the PAFC systems were compared to other co-generation systems especially when the combined cycle was used, i.e. the use of the generated heat. The transient efficiency change with a start-up process results are summarized in Figure 5.

Hart [51] presented a thermodynamic model to calculate the electrical and thermal energy generated due to the electrochemical reactions for different fuels and cell

types.

White [36] studied the viscous laminar and turbulent internal flows. Karlekar and Desmond [37] analyzed heat transfer rates in different configurations of mixed and non-mixed heat exchangers and provided several mathematical models to calculate the effectiveness as a function of the heat exchanger design, flow rates and conductance of the components. Also, a complete convective and conductive heat transfer analysis was presented for different boundary conditions of flow over a flat plate and in tubes. In addition, several techniques to determine the heat transfer coefficient were discussed.

Several accurate methods are available currently to measure experimentally the convection heat transfer coefficient. One of the most accurate methods is to use electrically conducting wall coatings and sense the change in current intensity at different locations. Omega [66] employed carbon impregnated coating on plastic plates and gold vapor deposited on a polyester sheet. Bailey Control [67] utilized infra-red photos of the cooled plates to determine the transient heat transfer coefficient and temperature equilibrium. One of the less expensive and less accurate methods of measuring the local convective heat transfer coefficients is to employ electrically heated plates. The major source of error is the energy loss through radiation which is very difficult to evaluate as concluded by Hart [51]. In addition, electrically heated

stainless steel foils with surface thermocouples were used to measure the transient change of local heat transfer coefficient in a wind tunnel by Boyle [7]. The major source of error again is the radiation heat transfer to the surroundings. An important experimental method used in heat exchangers to measure the heat transfer coefficient is to monitor the fluid temperature and volumetric flow rate and use this information to calculate the change in enthalpy. The only concern when using this method should be the possibility of disturbing the flow and accuracy of the flow meter used.

The imperfect contact between fuel-cell plates and cooling plates in the fuel-cell stack causes thermal resistance that depend upon the pressure imposed on the whole stack. This thermal resistance is called contact thermal resistance. As mentioned before, this parameter must be considered in the calculation of the fuel-cell heat transfer rate.

This important thermal resistance is due to the absence of perfect contact between any two conductive surfaces and the existence of air gaps. Therefore, not all the solid volume in contact is available and a undirectional heat flow away from the contact surfaces will exist.

The instantaneous thermal contact resistance parameter can be calculated using the Fourier equations away from the interference location. Alkasab and Abdul-Aziz [13] measured the steady-state temperature variation of the fuel cell

plate at different thicknesses and at the fuel-cell plate cooling plate interferance. Brunont and Buckland [63] presented a study that demonstrates the effect of contact pressure and surface roughness on the value of the thermal contact resistance of cold rolled steel joints. The thermal contact resistance was found to decrease dramatically with reducing the surface roughness.

Pomerantrev [61] investigated the effect of thermal contact resistance on the heat flow and thermal stress in solids of revolution of arbitrary shapes. Barzely et. al. [64,65] analyzed the contribution of different metal combinations, using the same thicknesses, sample temperatures, heat flow direction and vertical pressure on the sample on the total value of the thermal contact resistance. The thermal contact resistance for a certain combination was found to increase with increasing the vertical pressure and depends heavily on the heat flow direction.

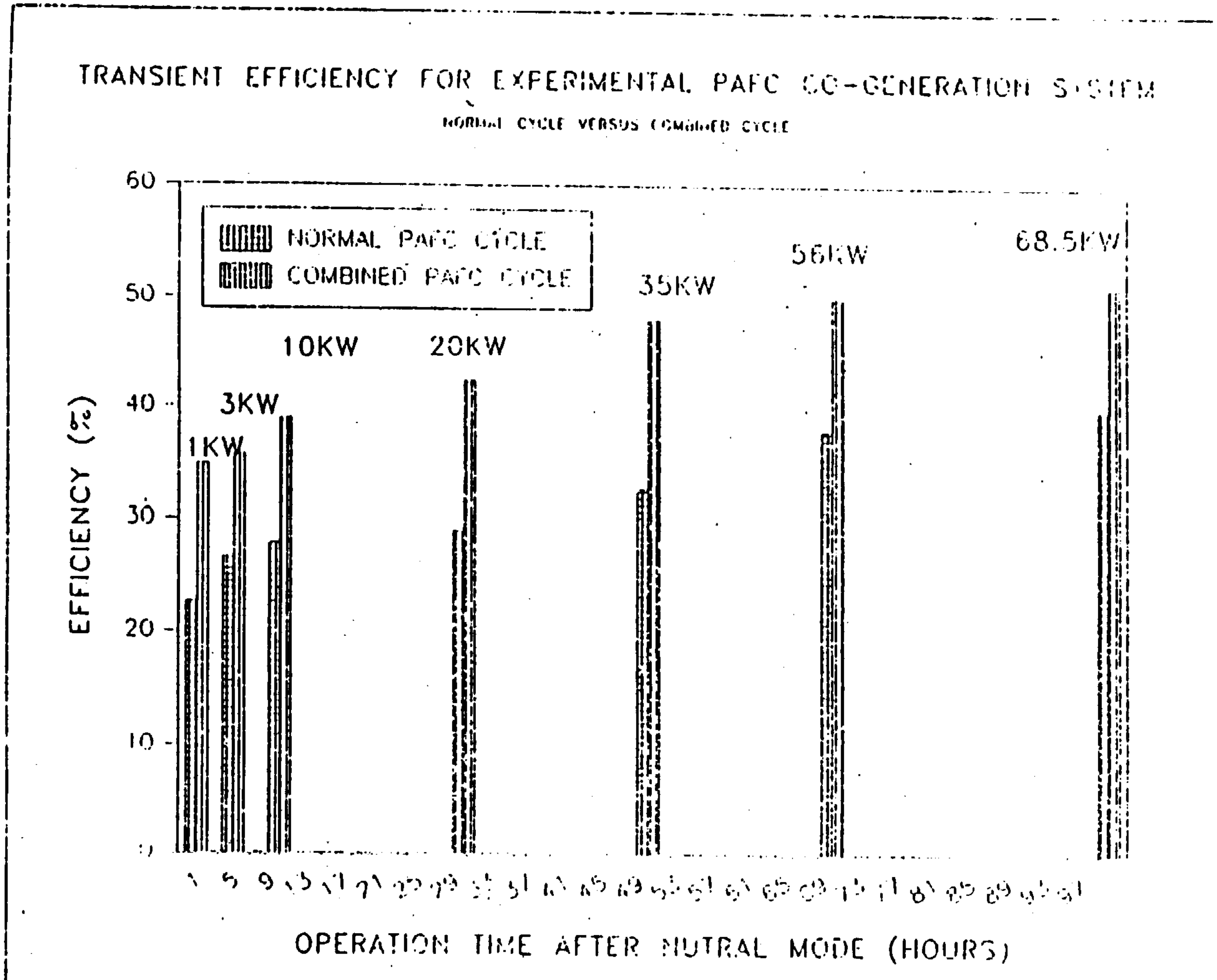



Figure 5. Transient Efficiency of an Experimental PAFC as a Co-generation System (Chart by Author).

# CHAPTER III

# EXPERIMENTAL SET-UP

In this chapter a summarized description of the experimental set-up used to generate the needed data and a brief procedural review will be presented.

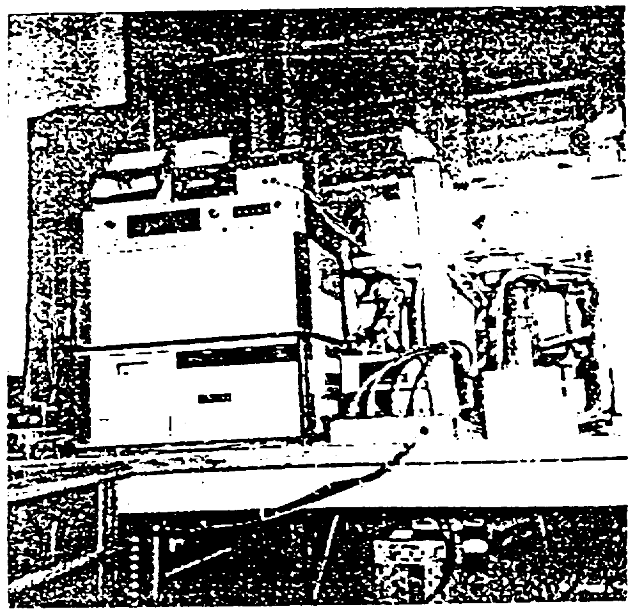
The experimental set-up, shown in Figure 6, consists of the following components:

1. Fuel-cell unit.
2. Special insulation
3. Power supply unit.
4. Cooling system.
5. Temperature measurement equipment.
6. Flow circulation and measurement equipment.
7. Data acquisition system.
8. Fuel cell stack pressure control and measurement equipment.

The experimental set-up components can be described as follows.

## 3.1 Fuel-Cell Unit

In order to simulate the heat generated by the chemical reaction inside the fuel cell during an actual transient operational condition of the PAFC, an electrical heat source, was placed inside the cell plate of the experimental



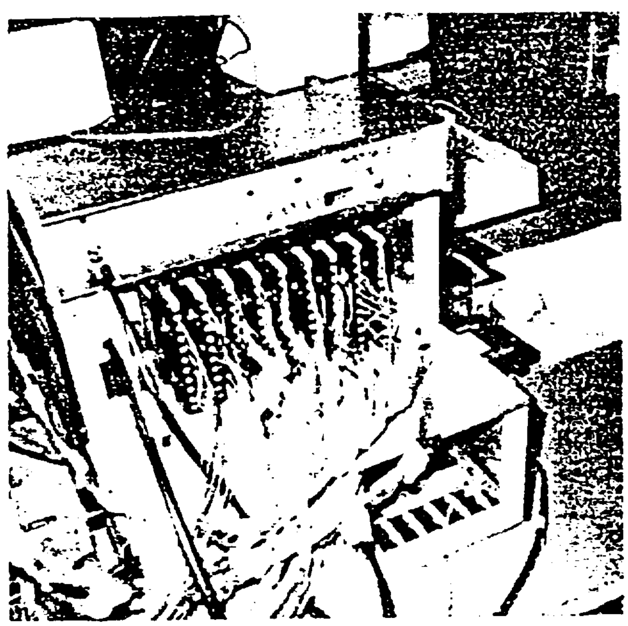


Figure 6. Experimental Fuel Cell Module and Interference With Measuring Equipment.

fuel cell model with the required power. The electrical heat source consists of four nickel-chromium alloy coils. The power provided to each coil can be controlled by changing the voltage across the coil.

The heating elements are sandwiched by the lower graphite plate, (o.3m x 0.41m x 9.5mm) and marinite plate from one side and the upper graphite plate (0.3m x 0.41m x 6.35mm) and a mica sheet from the other side. The marinite plate and the mica sheet were used basically to prevent any contact between the heating elements and the electrically conductive graphite plates. See Figure 7.

### 3.2 Power Supply Unit

The power supply unit has the ability to provide six independent variable subpower supplies. Also it can provide readings for the supplied voltage and amperage for each of those sources.

In order to measure accurately the voltage and amperage, a separate voltmeter and an ammeter were used at the interface of the power supply wires with the heating elements as shown in Figure 8. The energy level was simply calculated as follows:

$$P = I * E \tag{1}$$

$$E.E. = \frac{P}{A} \tag{2}$$

### 3.3 Special Insulation

The effect of heat losses from the control volume by

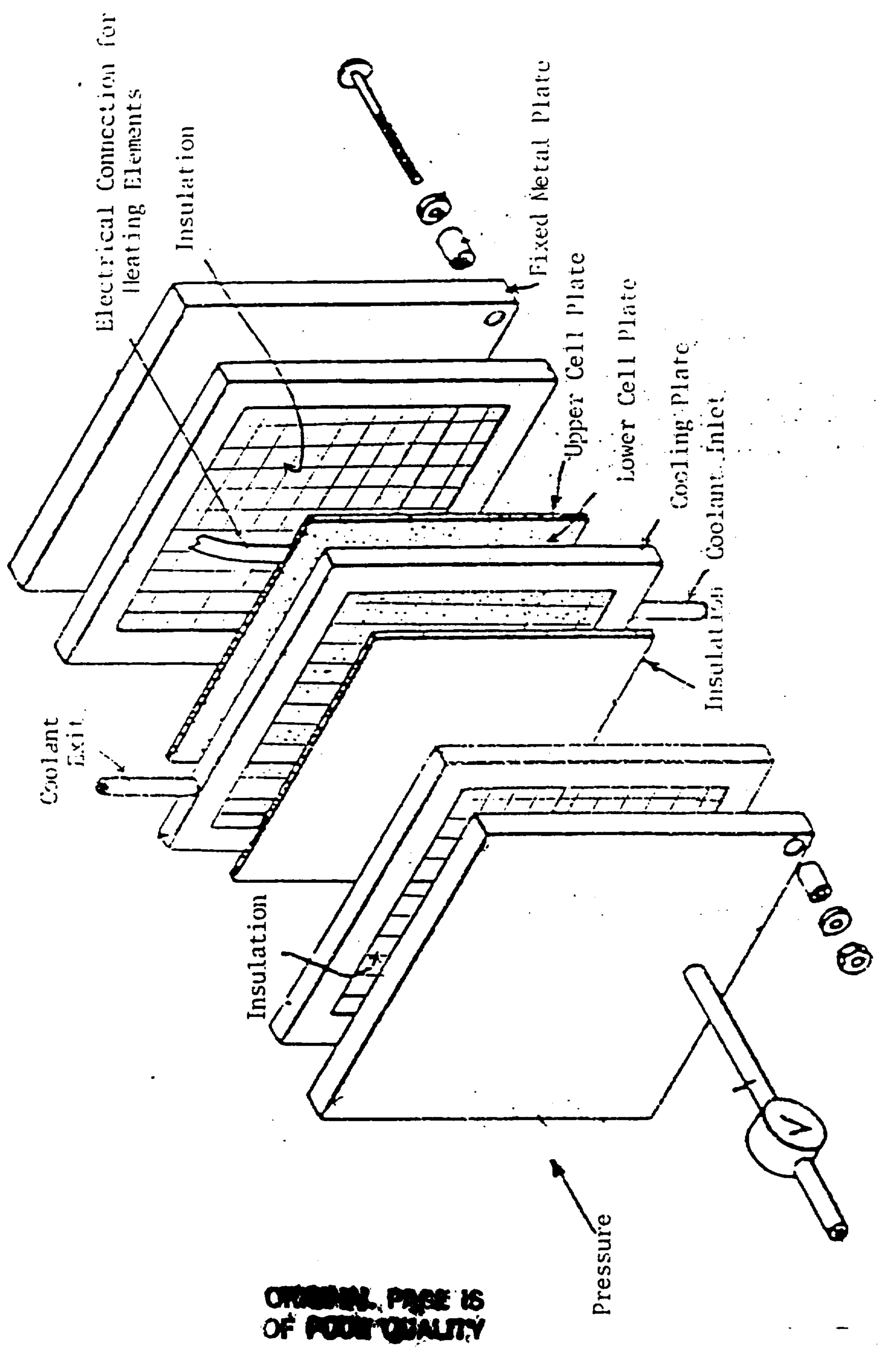
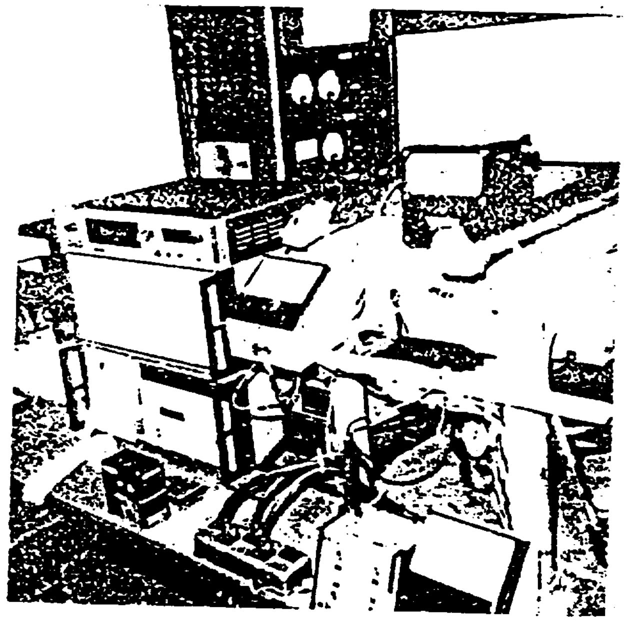



Figure 7 . Components of the Fuel Cell Module



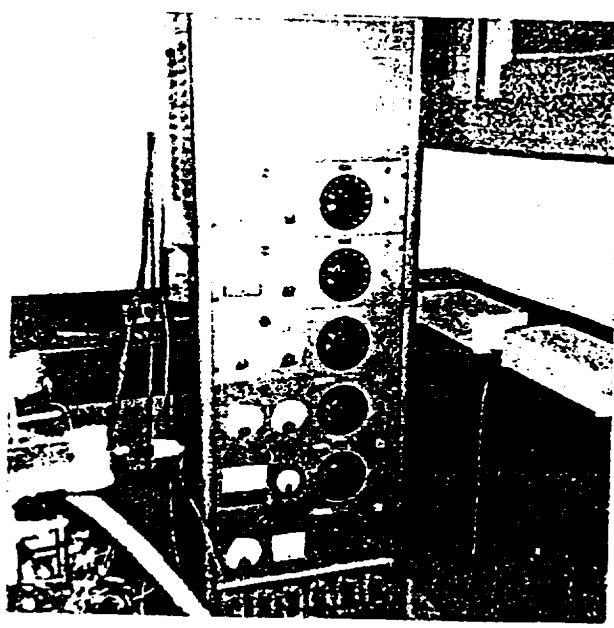


Figure 8. Power Supply to Fuel Cell Model.

radiation and convection was obvious on the accuracy of the gathered data. Therefore appropriate insulation was critically important to obtain acceptable results. Two Binder-Cement millboards were used above the upper graphite plate and below the cooling plate. Magnisa-85 insulation was used also to reduce heat losses above the upper millboard. Both of these insulations were used because of their ability to withstand high temperatures 300°C and above. Also all the clearences between the metal plates and the cell container walls were sealed by an insulation tape. In addition, insulation cement was used to seal any holes or clearence between the metal surfaces.

### 3.4 Cooling System

A serpentine cooling plate configuration was used for the removal of the generated heat, as shown in Figure 9. This configuration consists of a 9.5 mm in diameter copper tube sandwiched by the graphite plates. The required potential energy for the cooling fluid circulation was provided by a constant speed pump. A maximum flow rate of 5 gpm can be obtained. The complete water cooling system is shown in Figure 10 while the complete oil cooling system is shown in Figure 11. The different volumetric flow rates and in relation the different Reynolds number were provided by three adjustable valves that will extract some of the working fluid from the line entering the fuel-cell module.

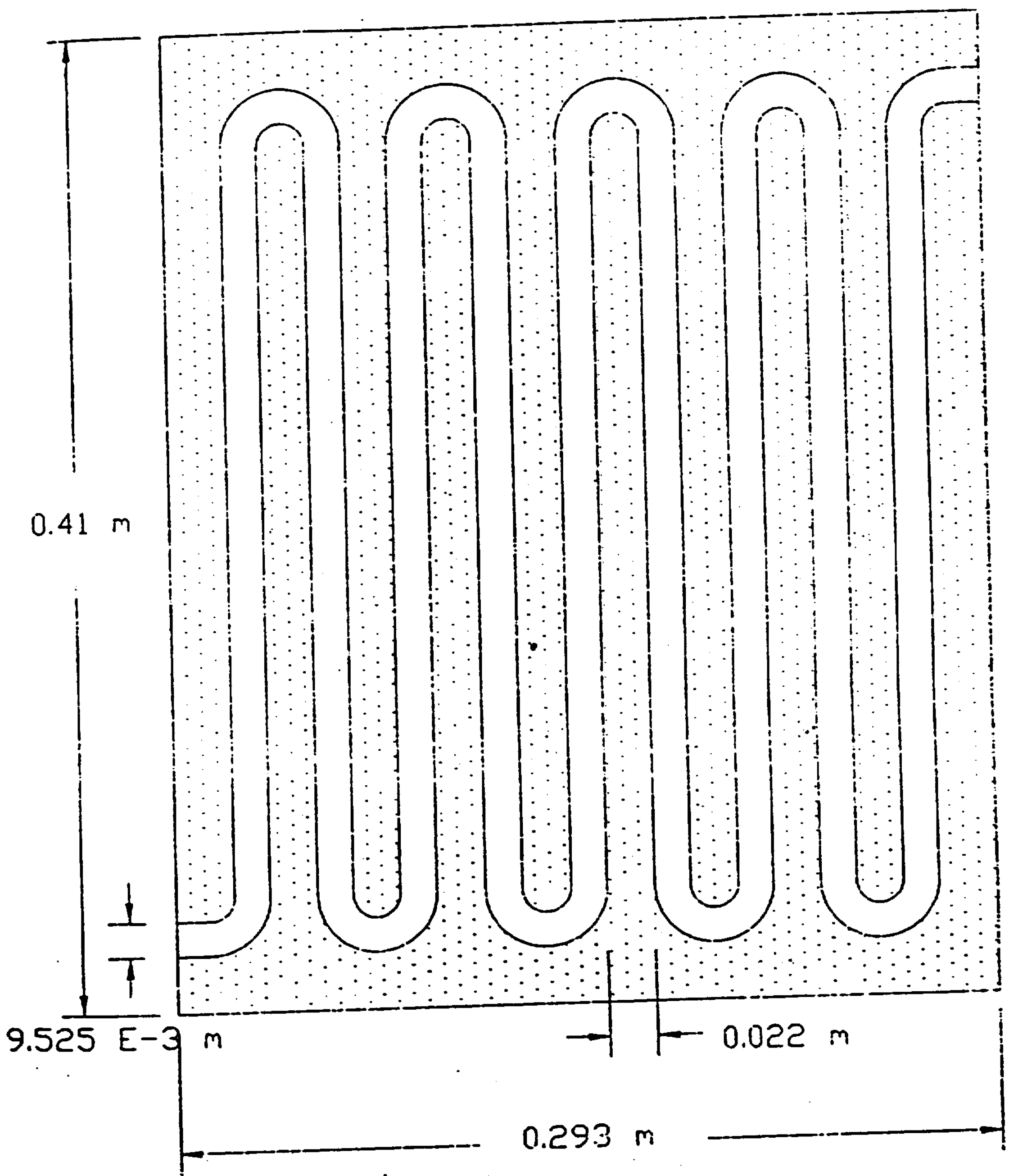



Figure 9. Serpentine Cooling Plate Dimensions

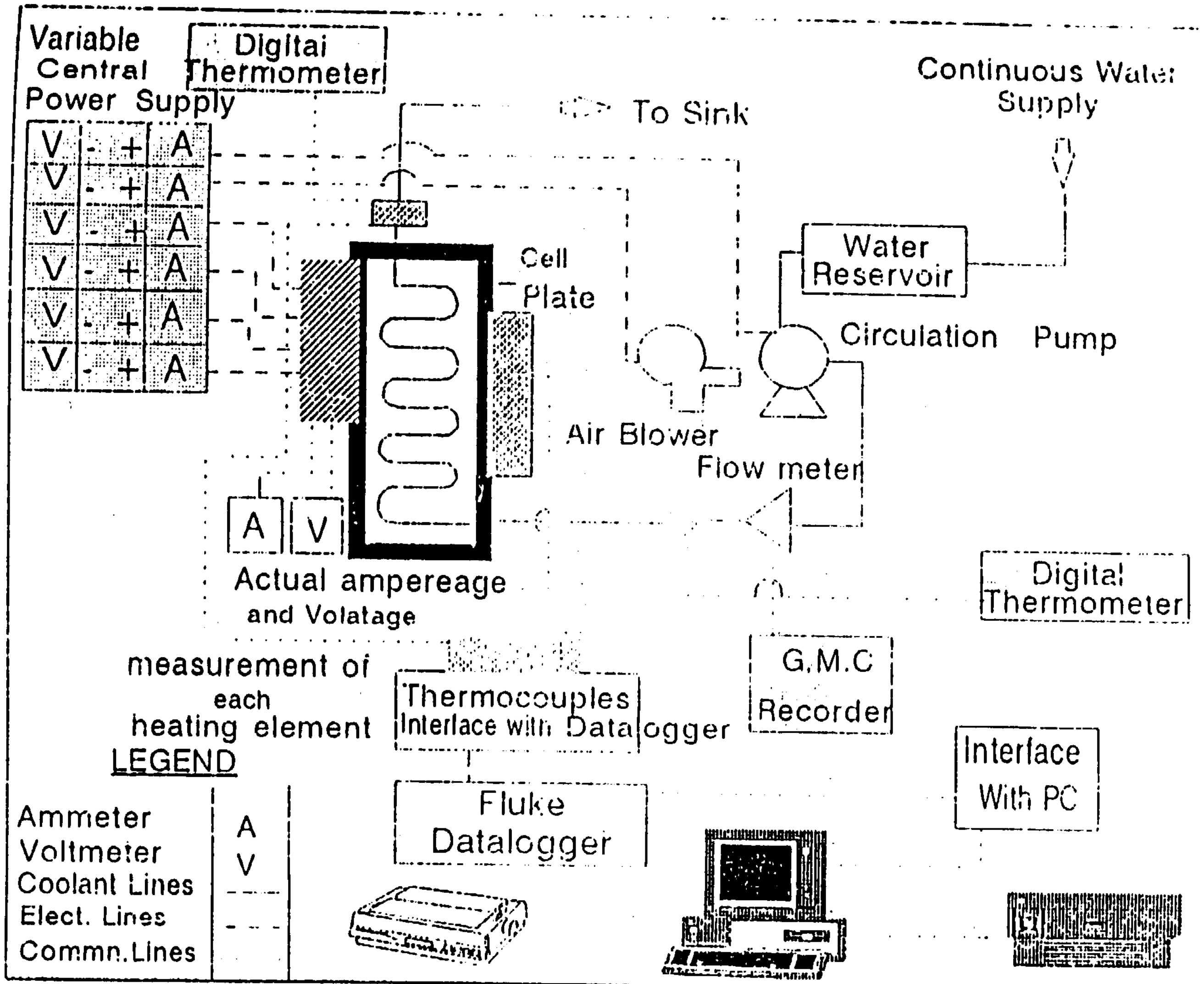



Figure 10. Layout of the Water Cooling System

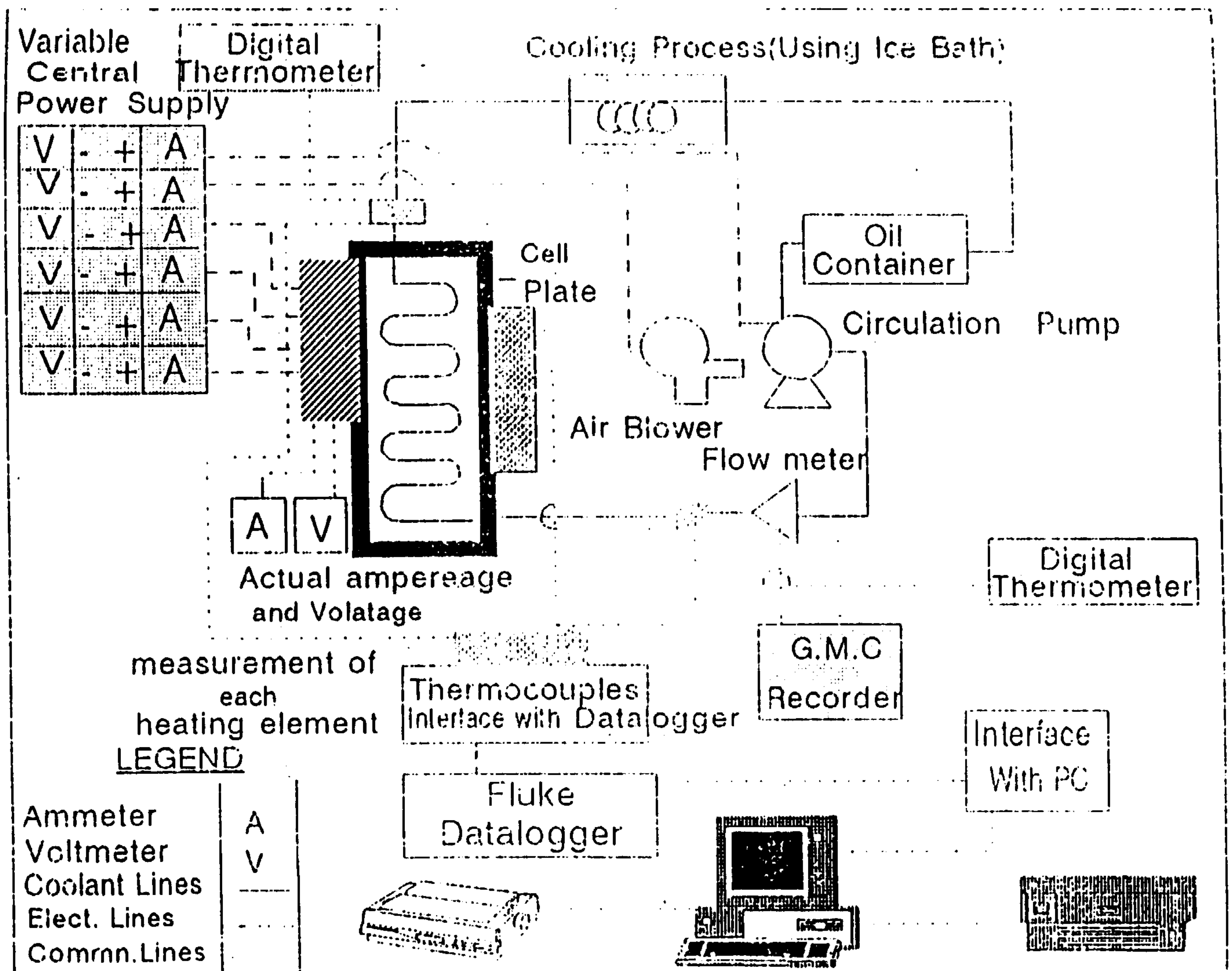



Figure 11. Layout of the Oil Cooling System

### 3.5 Temperature Measurement Equipment

0.25 mm diameter T-type thermocouples were used inside the fuel cell unit to monitor the temperature distribution. A Fluke (model 2201 A) scanner chassis and a Fluke (model 2200 B) data logger will serve as the data acquisition system. This reading can provide continuous logging of 100 temperature readings. The data logger was interfaced with a computer to monitor and record the following:

(a) The transient temperature distribution of the cell-plate.

(b) Temperature of the working fluid entering and leaving the fuel-cell module.

(c) Thermal contact resistance at the interface between the cell plate and the cooling plate.

### 3.6 Flow Measurement Equipment

The main flow rate can be read by using a flow meter and a turbine flow transducer. The second device has the ability to measure high temperature fluid flow, with high pressure with an accuracy of 0.4 gpm. This device was interfaced with the (MG Model 614A) counter to convert the frequency to digital readouts.

### 3.7. Data Acquisition System

An ARC (286 turbo) IBM compatible computer was used to monitor and record the time-dependent temperature profiles and the isotherm locations in conjunction with the coolant flow rate and power supplied to the heating element for the

determined time intervals during a simulation of a start-up or a shut-down operation. This interface was used to produce the Figures of the instantaneous locations of the isotherms using a (h/p) plotter. Each isotherm was expressed with a certain color. The figures produced also contained the Reynolds number of the test, the electrical energy level, temperature tolerance of the isotherms shown, the time interval and type of the coolant working fluid. The time interval for recording and interpreting the experimental instantaneous data was approximately 3.5 seconds. This guaranteed an accurate input to the results' calculations.

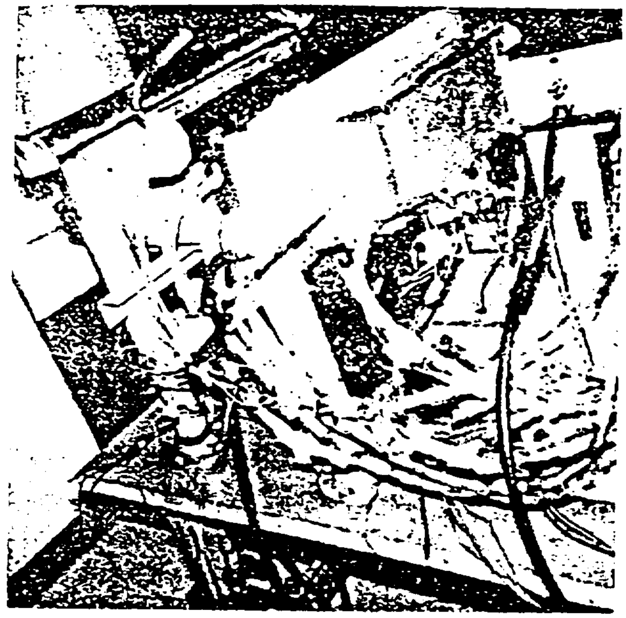
### 3.8 Fuel Cell Stack Pressure Control and Measurement Equipment

The pressure applied on the PAFC was simulated by sandwiching the fuel cell plates and the cooling fluid plate between two metal plates and applying pressure on the bottom one while fixing the other using a four ton hydraulic jack, as shown in Figure 12.

### 3.9 Testing Procedure

Testing procedures for both incompressible fluids used was carried out as follows:

(A) **Water Coolant**: An open cooling system was used, a reservoir was filled continuously with water between 21°C and 25°C. Then the coolant was pumped through the fuel cell. At the beginning of the test (time = 0) the four heating elements were provided with 1500 $W/m^2$, the coolant circulation pump and



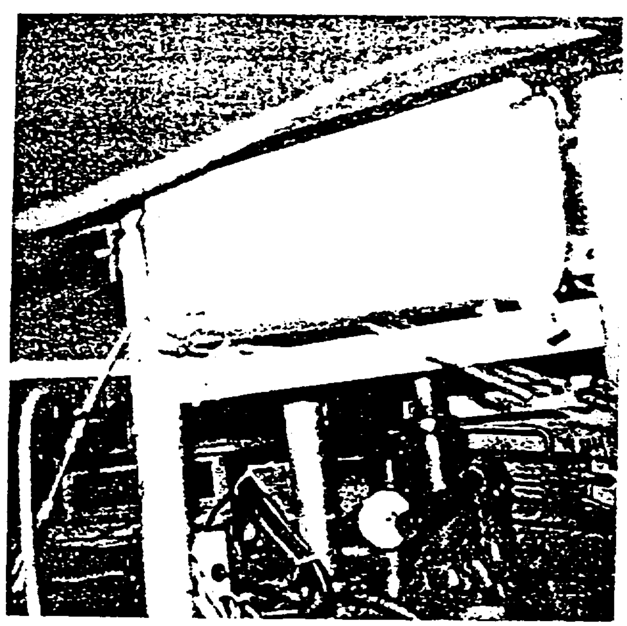


Figure 12. Fuel Cell Stack Pressurizing System.

valves, and the fuel cell stack pressure were adjusted for the test. An air blower was used to cool the circulation pump from overheating due to the long continuous runs. The power provided to the cell was gradually increased throughout the considered time intervals.

The temperature profile of the fuel cell was monitored and recorded continuously every one or five minutes. The figures produced provided instantaneous information about the fuel cell and the cooling system during the transient start-up process and through the shut-down process. Reynolds number for a whole test was kept constant throughout the two transient processes. Also, the pressure was kept constant during both processes. On the other hand, the power provided to the four heating elements were varied as follows to simulate the transient heat transfer process during start-up process and shut-down process. See Figure 13 and Figure 14.

1) Time intervals (1 through 2): the maximum power provided was 1500 $W/m^2$.
2) Time intervals (3 through 4): the maximum power provided was 2250 $W/m^2$.
3) Time interval (5 until reaching steady state): the maximum provided power was 3000 $W/m^2$.
4) Time intervals (steady state through 8): the minimum provided power was 2250 $W/m^2$.
5) Time intervals (9 through 10): the minimum provided power was 1500 $W/m^2$.

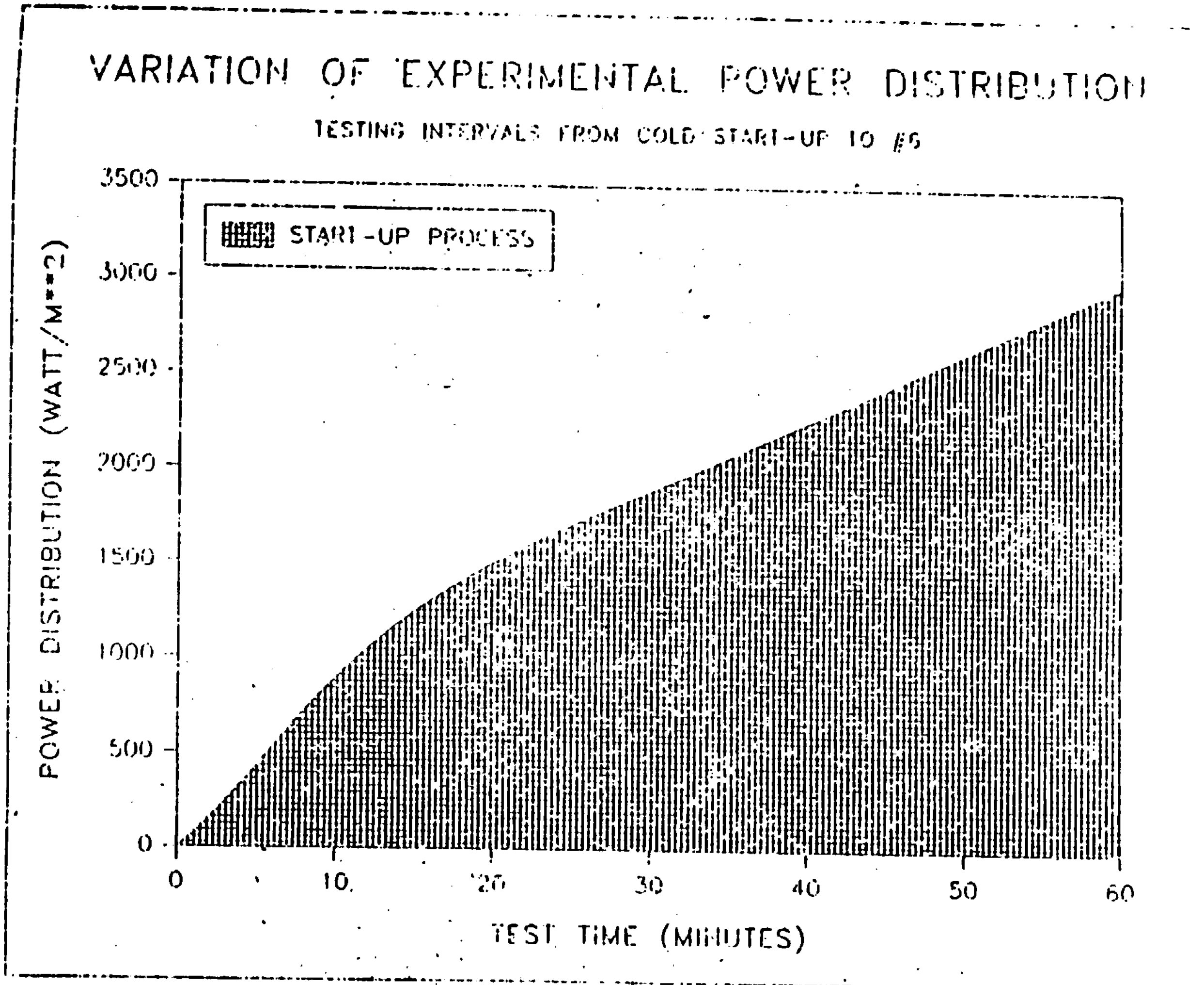



Figure 13. Experimental Power Distribution During the Considered Start-Up Processes.

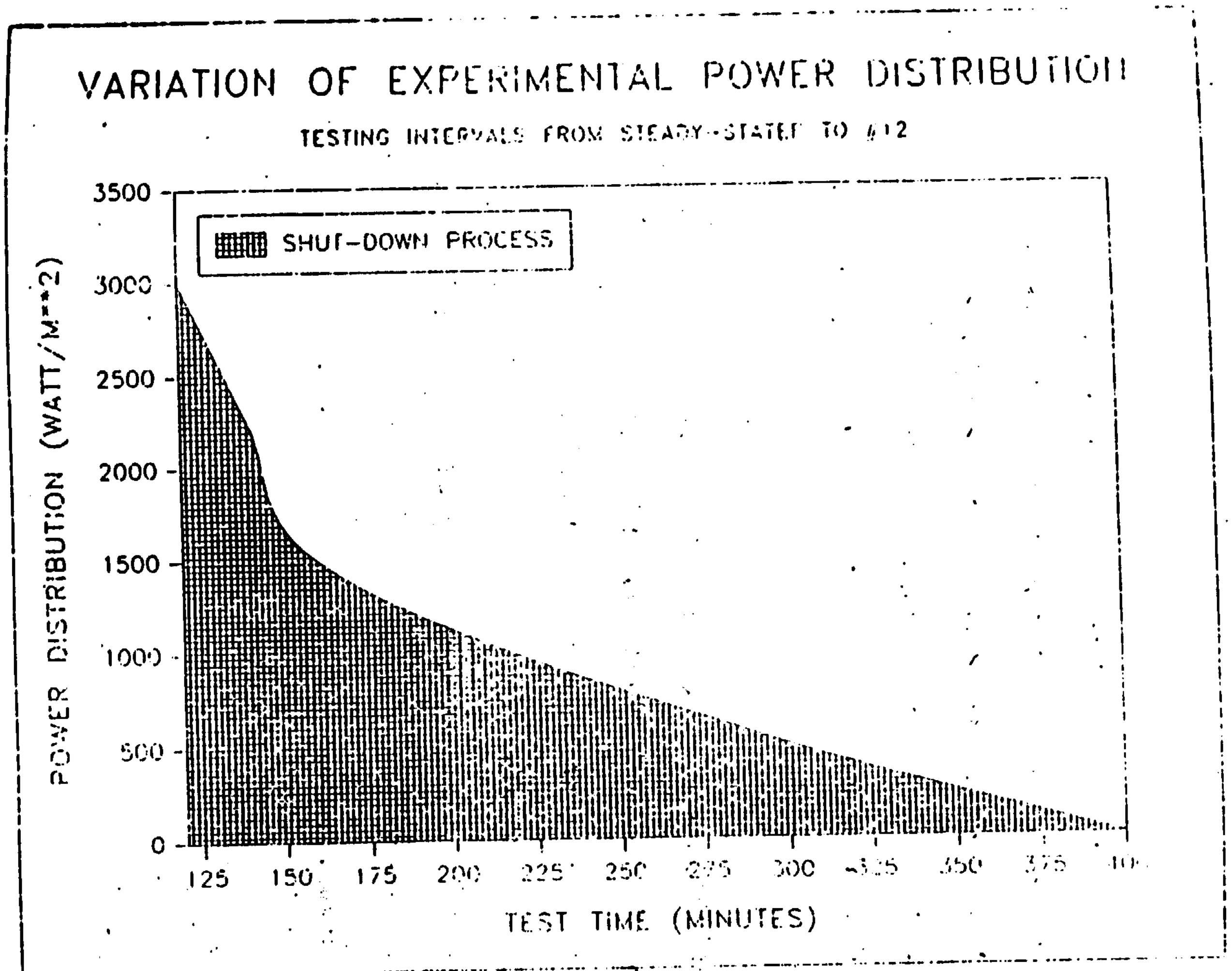



Figure 14. Experimental Power Distribution During the Considered Shut-Down Processes.

6) Time intervals (11 through 12): the minimum provided power was 0 $W/m^2$.

The mass flow rate was verified from 16 Kg/hr to 88.2 Kg/hr, while the stack pressure was varified from 0 KPA to 3500 KPA.

B) <u>Oil Coolant</u>: A closed cooling system with a secondary cooling system was used where the oil inlet temperature was kept approximately between (25°C and 26°C). The same testing procedure was followed. Also the same variation of stack pressure was used, but the Re number was increased from 15 to 80.

### 3.10 Interface Temperature Differential Measurements

The temperature differences due to imperfect surface contact were determined by twelve thermocouples located at and around the interface of the cell plate and the cooling plate as shown in Figure 15. Graphite powder was spread between the two plates to reduce air gaps and achieve better contact. The cooling plate thermocouples are attached to the cooling piping to measure the surface temperature.

### 3.11 Experimental Results Accuracy

Due to the instruments' accuracy and other factors there was an error percentage to be accounted for when representing the results. Accuracy is defined as the maximum amount by which a certain measurement differs from the true value, or

$$\text{Accuracy} = (M_m) - M_a$$

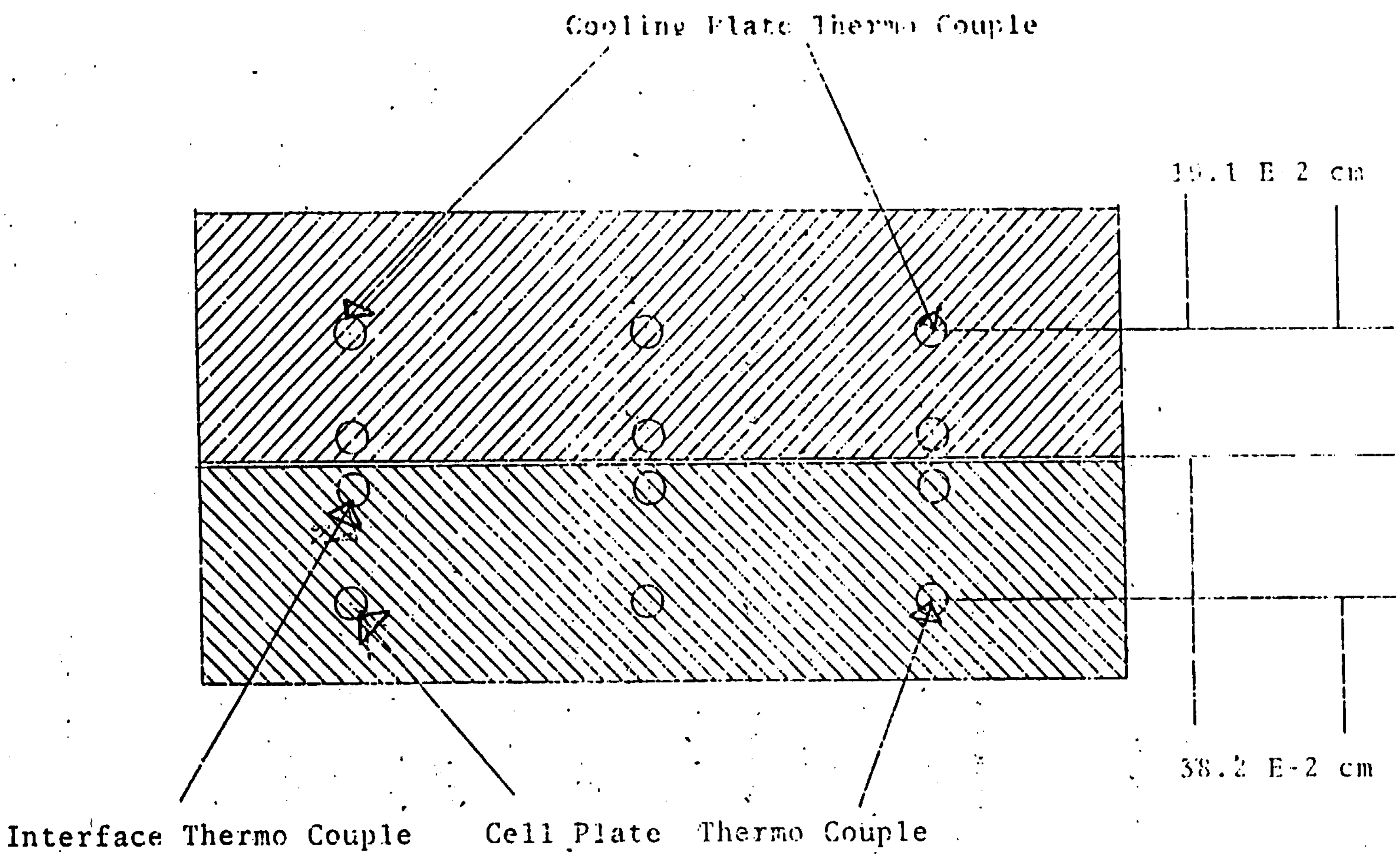



Figure 15. Location of Interferance Temperature Differential Thermocouple

Percent accuracy based on reading is

$$A = \frac{M_m - M_a}{M_a} * 100$$

where:

$M_m$ = maximum or minimum measurement,

$M_a$ = Actual value.

3.11.1 Instrumentation Error

The important instrumentation error can be summarized as follows.

3.11.1.1 Thermocouple Reading Accuracy

The thermocouple accuracy is considered the most important source of error that will affect the temperature distribution plots, the convection heat transfer coefficient, Nusselt number and overall heat transfer calculation. But this error has a significant effect on the effective temperature drop measurements which are used to determine the thermal contact resistance. The percentage of this error was determined by repeating certain tests with the same operation conditions, i.e. applied pressure, time interval versus supplied electrical energy for both incompressible coolants. The maximum error due to the thermocouples readings was found to be approximately 0.6 °C to 0°C, the manufacturer specfied that the error for T-type thermocouples are 0.75% or 1°C over zero °C.

3.11.1.2 Data Logger Readings Accuracy

Two factors affected remarkably the accuracy of the data

logger reading.

(a) Data logger input.

The minimum error was 0.5% as specified by the manufacturer. Also, on one occasion the machine had to be calibrated again after an electronic failure due to an electrical surge.

(b) Specified recording time intervals.

Since all the tests considered are transient tests therefore the selected length of the time interval should be as short as possible to avoid any significant change in the internal energy and other time dependent thermodynamic properties of the system. The time interval for the data logger to monitor all the thermocouples including the working fluid inlet and outlet thermocouples was approximately 3.5 seconds. This time interval was found to be very accurate because the change in the coolant outlet temperature during this time interval was nearly zero.

#### 3.11.1.3 Voltage and Amperage Readings

The accuracy of the ammeters and voltmeters mounted in the power supply unit was 4.0% while the digital multimeter accuracy was 2.1% as specified by the manufacturer. Actually the voltage and ampere readings were more accurate because the power unit readings were checked again by the cell instrumentation.

#### 3.11.1.4 Pressure Gauge Readings

The pressure gauge accuracy was 0.1%. The maximum

expected error when the highest applied pressure was used was ±35 KPa.

3.11.1.5 Volumetric Flow Rate Measurements

As mentioned before the combined accuracy of the flow instrumentation was found to be ± 0.4 gpm or maximum combined error of 2.3%.

3.11.2 Heat Exchange with the Surroundings

The unaccounted for heat transferred by radiation convection and conduction to the surroundings is very difficult to calculate. However if the rate of heat transfer was significantly high it could negatively affect the accuracy of the final results that depends on the evaluation of the transient thermal energy transferred by the cooling fluid. Several tests were carried out utilizing both working fluids under different operation conditions. The maximum heat transfer was found to be 17.5 watt where using 3000 $w/m^2$ and maintaining a steady state operating condition with minimum Re number and maximum pressure. This is 7.792% of the internal heat generator simulated by the supplied electrical power. Additional insulation was added as described by Chapter III to reduce the heat loss. The heat transfer rate to the surroundings was reduced to a maximum of 9.1 Watts which is 2.466% of the supplied power.

3.11.3 Human Error

The human error is an important factor in the accuracy

of the final results. The effect of such error in this experiment was observed during the following.

(a) Voltage and amperage readings.

(b) Obtaining exactly the required stack pressure.

(c) Supplied power variation for the four electrical circuits used during a very short time interval.

(d) To maintain continuously throughout the testing time interval the exact volumetric flow rate.

(e) To maintain a constant room temperature during all the tests.

CHAPTER IV

# MATHEMATICAL MODEL OF TRANSIENT HEAT TRANSFER IN THE FUEL-CELL STACK

The thermal energy generated in the fuel cell should be removed continuously to prevent accumulation of heat which could lead to thermal stress, lower efficiencies and even structural failure. Therefore, proper design of the cooling system is vital to the operation and performance of any fuel cell power system. In this chapter the effect of the expected transient operation conditions' effect on the cooling system performance were investigated with water and oil as coolants.

## 4.1 Transient Heat Transfer Analysis for the Cooling System

This section will summarize the formulation employed to generate the needed results utilizing the gathered experimental data during the transient process considered using incompressible cooling fluids.

### 4.1.1 Heat Transferred to the Cooling Fluid

Applying the first law of thermodynamics for the considered case, at any instant of time during the transient process, the energy balance equation for the cooling fluid can be written as follows; see Figure 16.a.

$$(\dot{Q}(t))_{c.s.} = \left|\frac{d\ E(t)}{dt}\right| + \left[\dot{m}_e(t) * H_e(t) - \dot{m}_i(t) * H_i(t)\right] \qquad (3)$$

But, $\dot{m}_e(t) = \dot{m}_i(t) = \dot{m} =$ constant for a given test

$$(\dot{Q}(t)_{c.s.} = \left|\frac{dE(t)}{dt}\right| + \dot{m}\ C_p\ (T_{be}(t)-T_{bi}(t)) \qquad (4)$$

Also

$$\frac{dE(t)}{dt} = \frac{m(t_2)*u(t_2) - m(t_1)*u(t_1)}{\Delta t} \qquad (5)$$

where:

$\dot{Q}_{c.s.}(t)$ = Heat transferred to the cooling fluid, as a function of time.

$\dot{m}_i(t)$ = Instantaneous mass flow rate entering the coolant channel, constant for a given test.

$m(t)$ = mass inside the cooling plate at time (t).

$H_i(t)$ = Instantaneous total enthalphy of the mass flow rate (i) entering the cell.

$\left(\frac{dE(t)}{dt}\right)$ = transient change of the control volume internal energy, which includes the cooling plate and the upper part of the cell plate.

$T_{bi}(t)$ = Cooling fluid bulk temperature entering the cell.

$T_{be}(t)$ = Cooling fluid bulk temperature leaving the cell.

$\dot{m}_e(t)$ = Instantaneous mass flow rate leaving the cell from location (e), constant for a given test.

$H_e(t)$ = Instantaneous total enthalpy of the mass flow rate (e) leaving the cell.

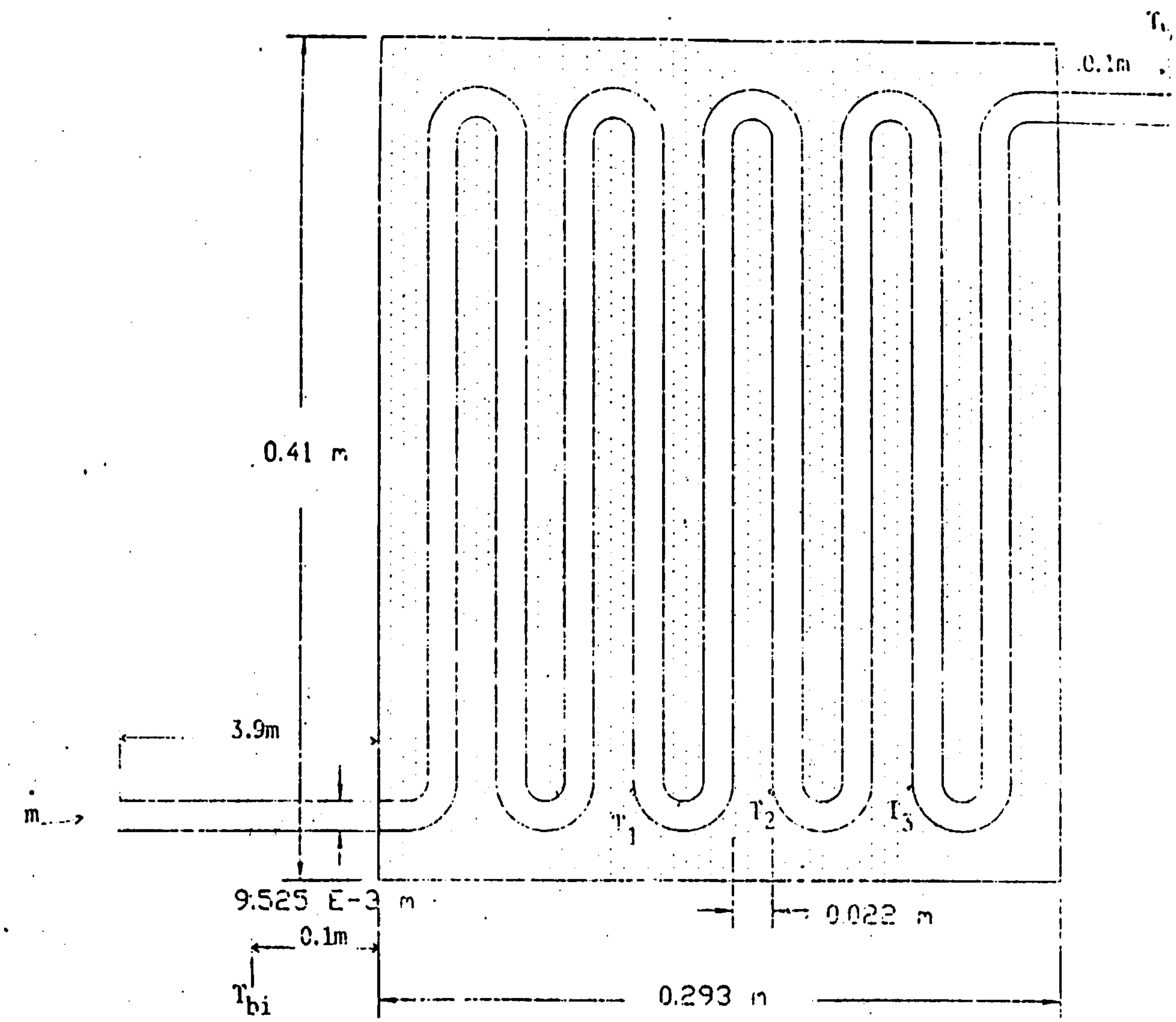



Figure 16. Heat Transfer Thermocouple Locations.

$C_p$ = Specific heat at constant pressure.

$u(t)$ = Cooling fluid internal energy at time (t) inside the control volume.

### 4.1.2 Transient Convective Heat Transfer Coefficients and Nusselt Number

The energy transferred to the cooling system can be utilized to accurately determine the transient local convective heat transfer coefficient as follows:

$$((\dot{Q}(t))_{c.s.} = h(t) * A_{c.s.} * [T_w(t) - T_\infty(t)] \tag{5}$$

where:

$h(t)$ = instantaneous convective heat transfer coefficient between tube surface and coolant.

$A_{c.s.}$ = available heat transfer surface area of the cooling channel.

$T_w(t)$ = instantaneous average wall surface temperature of the cooling plate. copper tube, obtained from the thermocouples welded to the coils.

$T_\infty(t)$ = instantaneous average bulk coolant temperature.

The instantaneous average wall surface temperature is the average of all the thermocouples' readings welded to the cooling coil for a certain measurement (see Figure 17.a).

The temperature variation of those thermocouples was found to be linear as a function of the coil length for any given test (refer to Appendix). The instantaneous average bulk temperature also called the mixed mean average temperature is basically the ratio of the total thermal energy crossing the tube in a unit time over the heat capacity of the fluid crossing the same section in a unit of time. This temperature was calculated utilizing the experimental data of selected laminar and turbulent cases for both fluids taking into consideration the change of the thermal diffusivity of the fluid ($\alpha = \frac{K_c}{\rho C_p}$).
Also, for the laminar flow, the laminar entrance length was estimated using the average results of the Blasius, Sparrow and Schlichting equation in addition to the thermal entry length. The results of the average bulk temperature employing the forced convection of circular tubes equation provided by references [14] and [38] were compared to the average of the entrance and exit temperatures of the control volume. This comparison indicated that the difference was in the range of 1.5% to 3%. Therefore, the average bulk coolant temperature was used in the final calculations performed by the experimental monitoring system. The experimental convective heat transfer coefficient (h(t)) was calculated from equation (5), as follows:

$$h(t) = \frac{((Q(t))_{c.s.}}{A_{c.p.s.}(T_w(t) - T_\infty(t))} \tag{6}$$

Then the experimental transient Nusselt number was calculated as follows:

$$Nu(t) = \frac{h(t) * D}{K_c} \tag{7}$$

### 4.1.3 The Experimental Overall Heat Transfer Coefficient

The experimental transient overall heat transfer coefficient for the control volume defined in the previous section was determined as follows:.

Since,

$$(\dot{Q}(t)_{c.s.} = U(t)*A*(T_e(t)-T_\infty(t))$$

Therefore:

$$U(t) = \frac{(Q(t))_{c.s.}}{A_c(T_e(t) - T_\infty(t)} \tag{8}$$

But it should be noticed that the transient overall heat transfer coefficient is considered: in the reciprocal of the sum of three resistances See Figure 17-b: the convection resistance, the conduction resistance, and the thermal contact resistance. U(t) can be expressed as follows:

$$U(t) = \frac{1}{\left[\left(\frac{X_1}{K}\right) + \left(\frac{1}{R_c(t))}\right) + \left(\frac{X_2}{K}\right) + \left(\frac{1}{h(t)}\right)\right]} \tag{9}$$

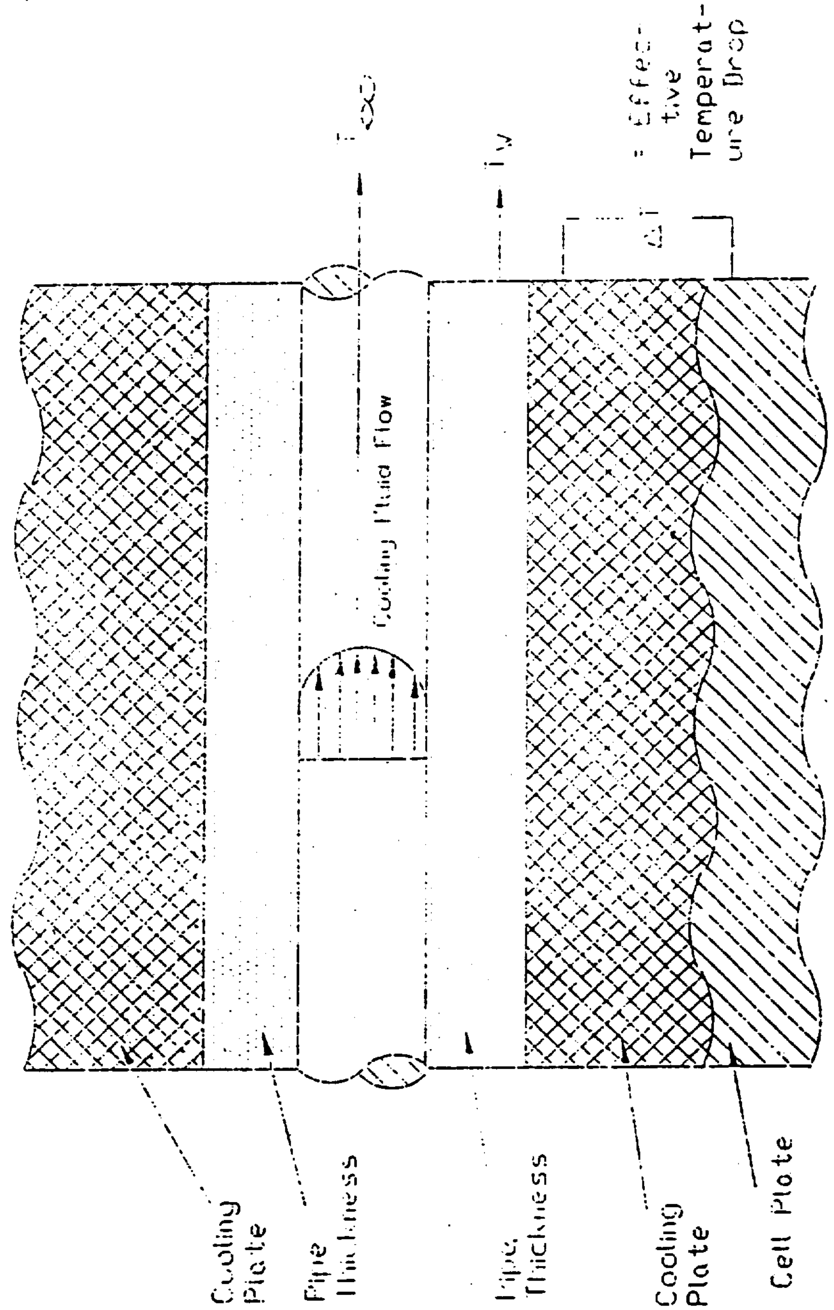



Figure 17-a. System Measured Temperature

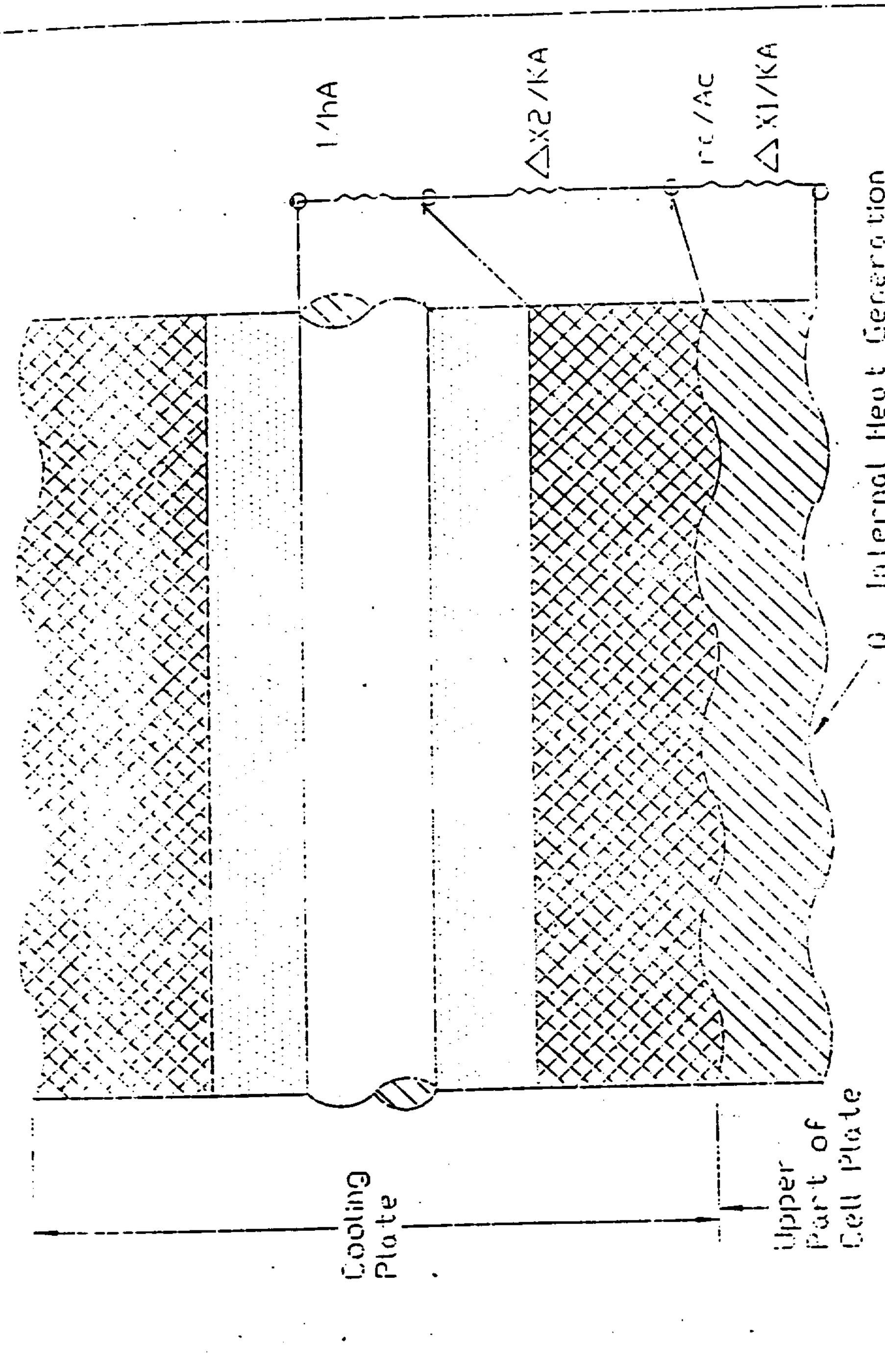



Figure 17-b. Thermal Resistance

The thermal contact resistance between the upper part of the cell plate and the cooling plate can be calculated as follows: (please refer to Figure 17.c).

$$Q = K_A \; A_c \; \frac{dT}{dx}\Big|_0^{L_1} = K_B \; A_c \; \frac{dT}{dx}\Big|_{L_1}^{L_2} \tag{10}$$

However, the instantaneous thermal conductance parameter (R) is defined as:

$$R_c(t) = \frac{q(t)}{\Delta T(t)}$$

when

q(t) = instantaneous heat flux (Q/A).

ΔT = effective temperature drop through the interference between the upper part of the cell plate and the cooling plate.

Substituting in equation (6):

$$R_c * \Delta T = K_A \frac{dT}{dx} = K_B \frac{dT}{dx}$$

or

$$R_c = \frac{K_A}{\Delta T} \frac{dT}{dx} = \frac{K_B}{\Delta T} \frac{dT}{dx} \tag{11}$$

The thermal contact resistance ($r_c$) is the inverse of ($R_c$):

$$r_c = \frac{1}{R_c} = \frac{\Delta T}{K_A \frac{dT}{dx}} = \frac{\Delta T}{K_B \frac{dT}{dx}} \tag{12}$$

Substituting equation (12) in equation (9), we will have the following:

$$U(t) = \frac{1}{\left[ \left(\frac{x_1}{K}\right) + \left( \frac{\Delta T(t)}{K * (\frac{dT}{dx})} \right) + \left(\frac{x_2}{K}\right) + \left(\frac{1}{h(t)}\right) \right]} \tag{13}$$

where:

$K_A$ = thermal conductance of the cell plate.

$K_B$ = thermal conductance of the cooling plate.

$u(t)$ = transient overall heat transfer coefficient of the control volume.

$A_c$ = contact area between cooling plate and cell plate.

$T_e(t)$ = T.A. = transient average temperature of the electrode.

$K$ = graphite conductivity (thermal).

$x_1, x_2$ = thickness in the X direction (please refer to Figure 17.c).

$r_c$ = transient thermal contact resistance.

$\Delta T(t)$ = effective temperature drop.

## 4.2 Experimental Results

In this section the experimental results collected previously will be analyzed and interpreted to determine the effects of the stack pressure and the cooling systems flow characteristics on the fuel cell heat transfer characteristics. The experimental results will be further used to formulate the mathematical correlations to simulate and express the heat transfer characteristics of the examined fuel cell module during transient operation conditions, start-up and shut-down.

### 4.2.1 Start-Up Process

Referring to section (4.1) of this Chapter, The value of h(t), Nu(t) and U(t) were determined by applying equations (6), (7) and (13) using the data gathered from the experimental set up.

#### 4.2.1.1. The Variation of the Transient Nusselt Number as a Function of the Cooling System Flow Characteristics

(a) Water Coolant (Re = 1250 to Re = 6167).

Experimental results demonstrated by Figure 18 indicates the dependence of the transient Nusselt number on the flow characteristics of the cooling system during a start-up process. Higher Nusselt numbers were calculated with higher flow rates.

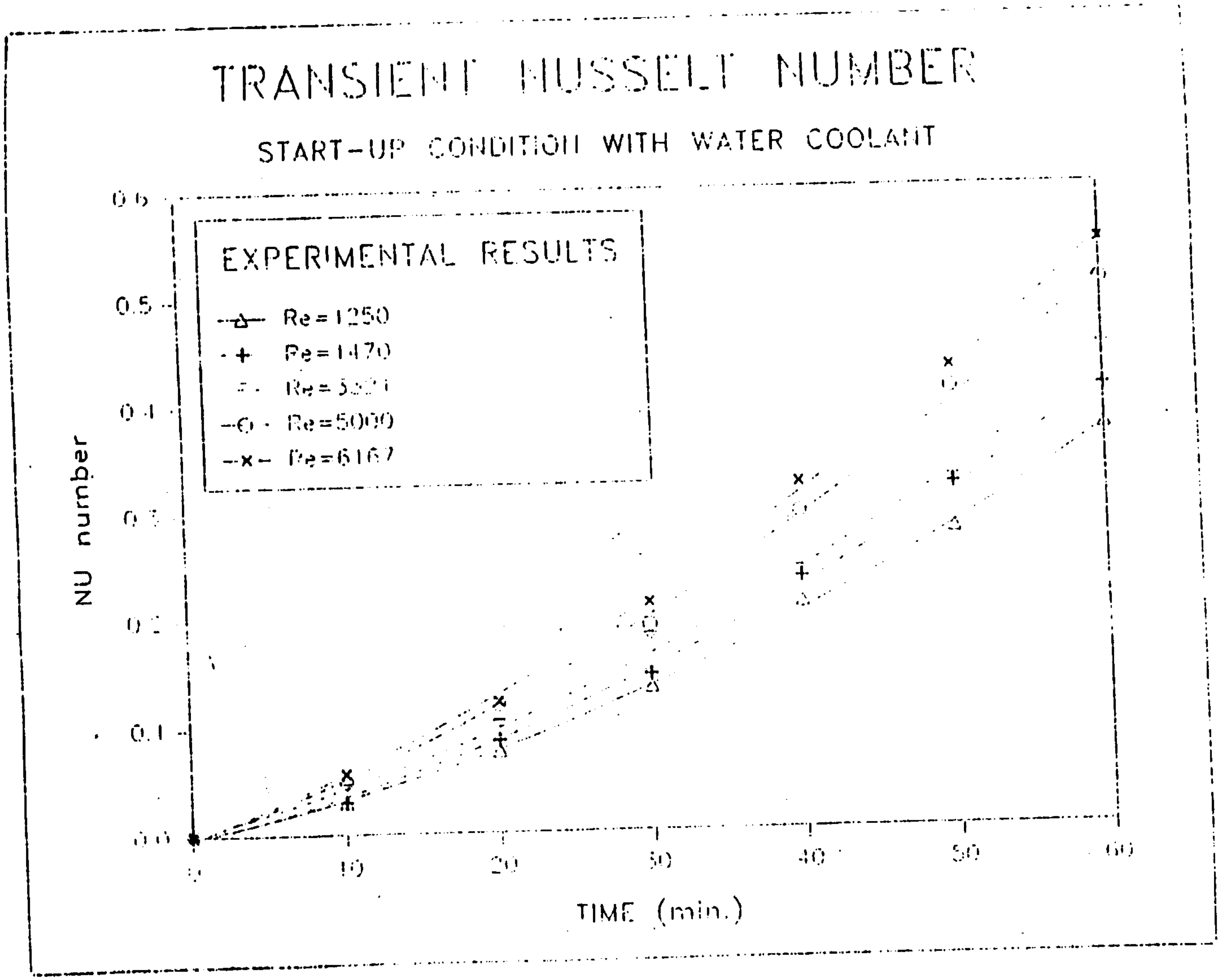



Figure 18. Experimental Transient Nuselt Number (Start-Up with Water Coolant).

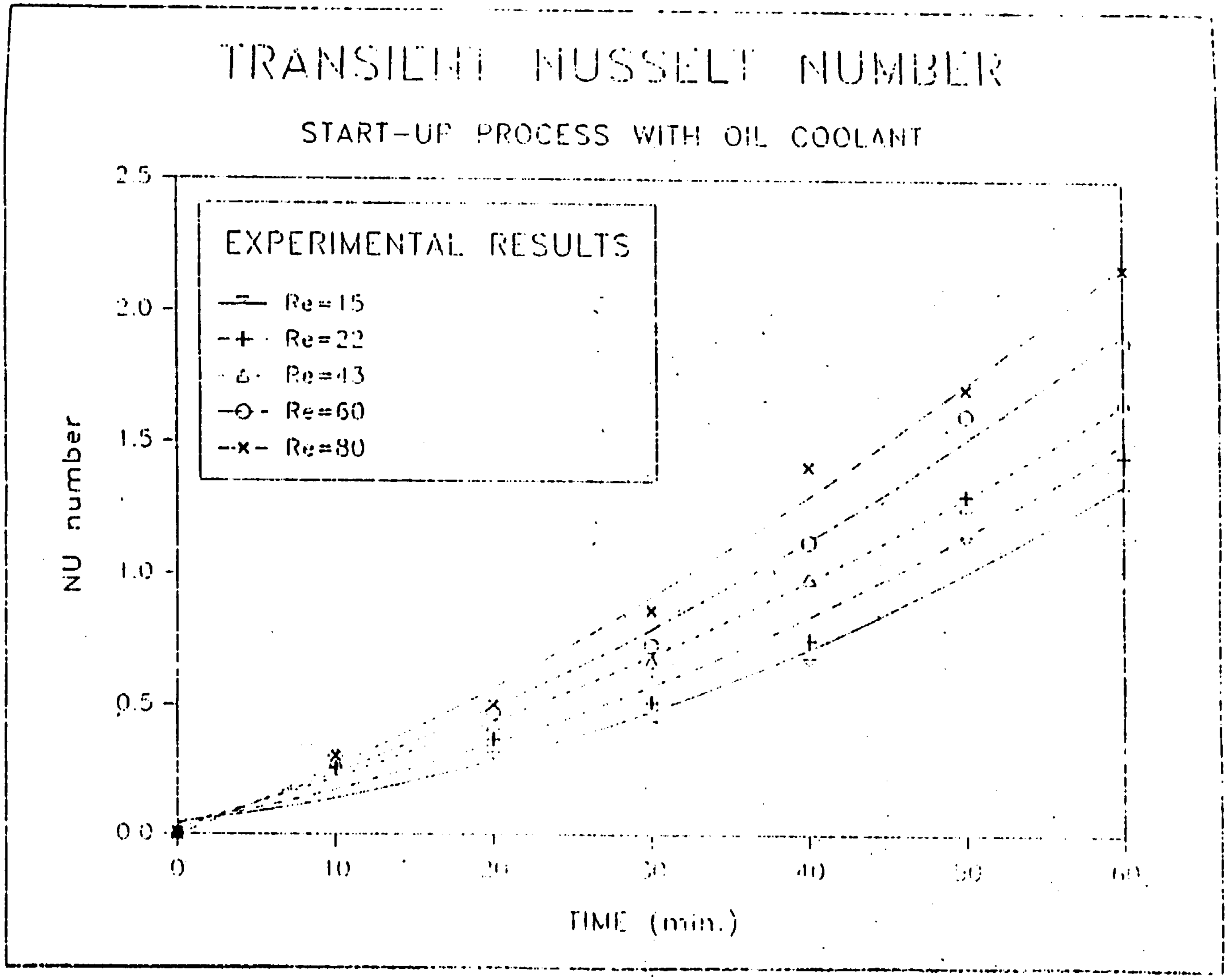



Figure 19. Experimental Transient Nusselt Number (Start-Up with Oil Coolant).

(b) Oil Coolant (Re=15 to Re=80).

Figure 19 demonstrates the variation of the Nu number during a start-up process using oil as a coolant.

#### 4.2.1.2. Measurements of the Transient Thermal Contact Resistance

As described in Chapter III, the thermal contact resistance was actually measured utilizing 12 thermocouples planted around the interface area to measure the temperature differential. Equation (12) was then used to determine the value of $r_c$ at any point in time. Figure 20 through Figure 22 shows the effect of the different considered stack pressures on the transient values of $r_c$. It should be noticed that a slight decrease in the rate of $r_c$ was observed with a higher Re number.

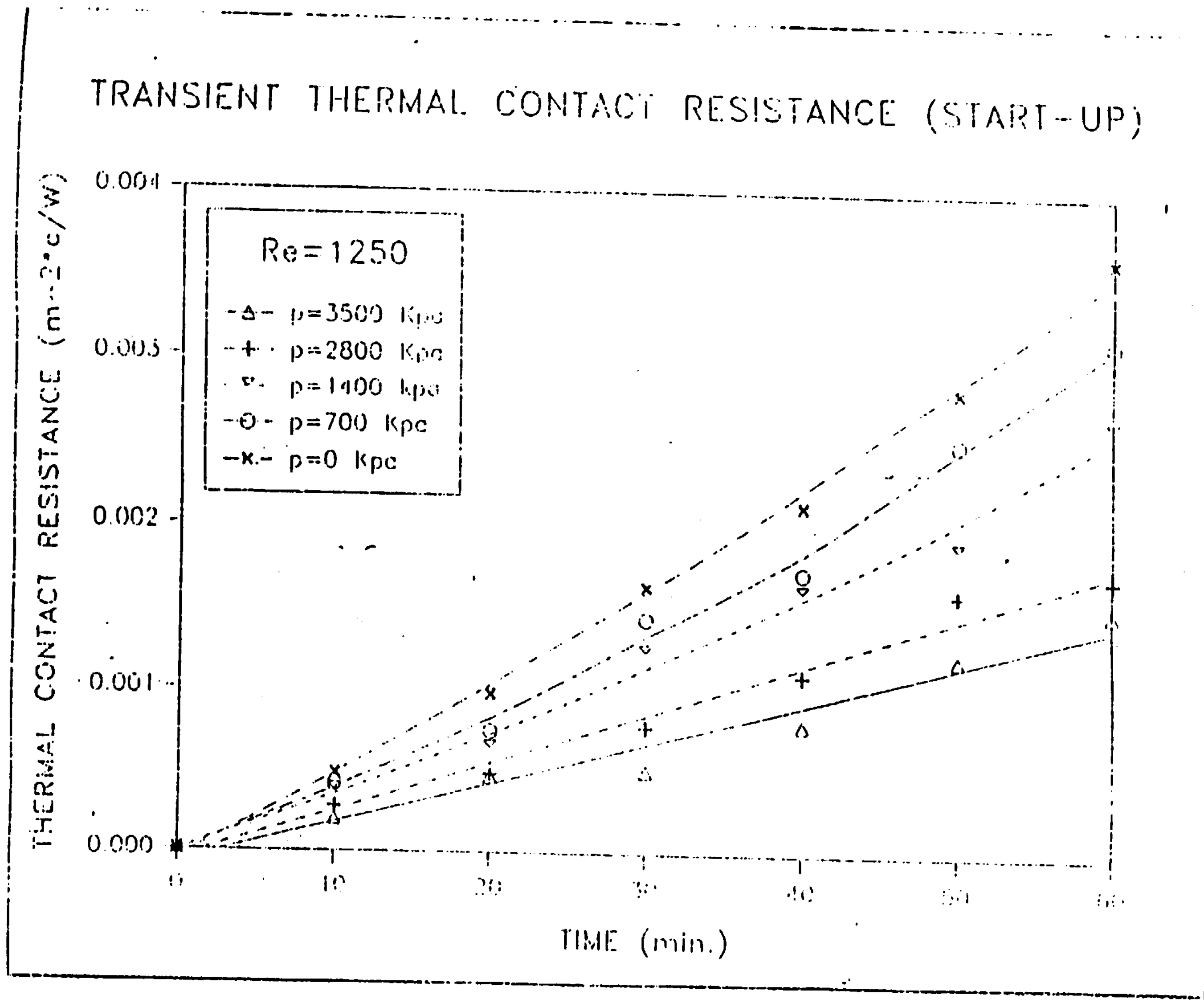



Figure 20. Experimental Transient Thermal Contact Resistance (Start-Up Condition with Water Coolant Re = 1250).

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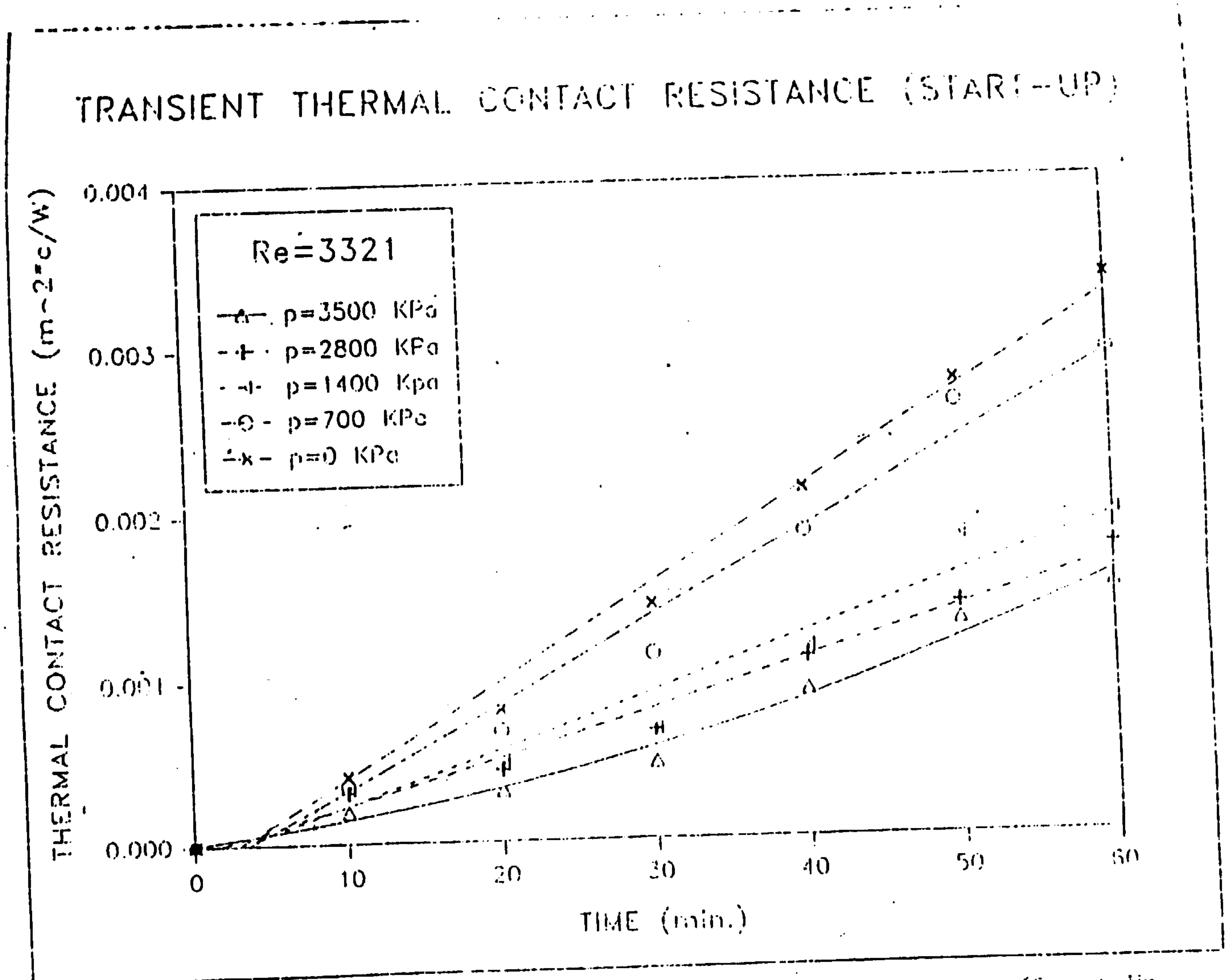


Figure 21. Experimental Transient Thermal Contact Resistance (Start-Up Condition with Water Coolant Re = 3321).

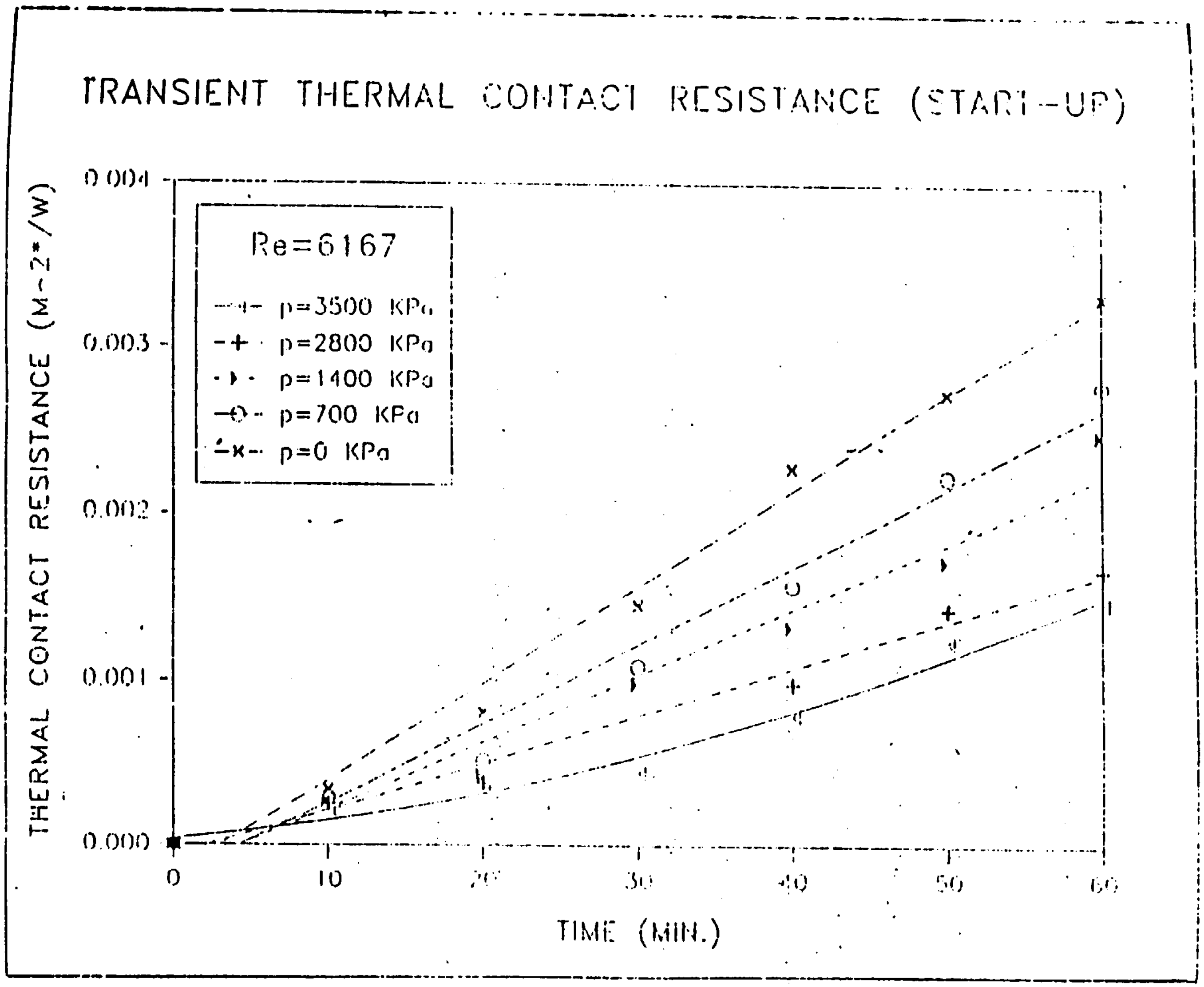


Figure 22. Experimental Transient Thermal Contact Resistance (Start-Up Condition with Water Coolant Re = 6167).

### 4.2.1.3 The Effect of the Stack Pressure and the Cooling System Flow Characteristics on the Transient Overall Heat Transfer Coefficient

(a) Water Coolant (Re = 1250 to Re = 6167).

Experimental results exhibited in Figure 23 through Figure 24 summarizes the experimental data gathered and the calculations from fifteen transient experimental tests which are part of the testing process that focused on investigating the heat transfer characteristics of the fuel cell during a start-up process. In each Figure the volumetric flow rate was kept constant for the five experimental runs to determine the overall heat transfer coefficient.

(b) Oil Coolant (Re=15 to Re=80).

Figure 26 through Figure 28 exhibits part of the experimental results during a start-up process using oil as a coolant.

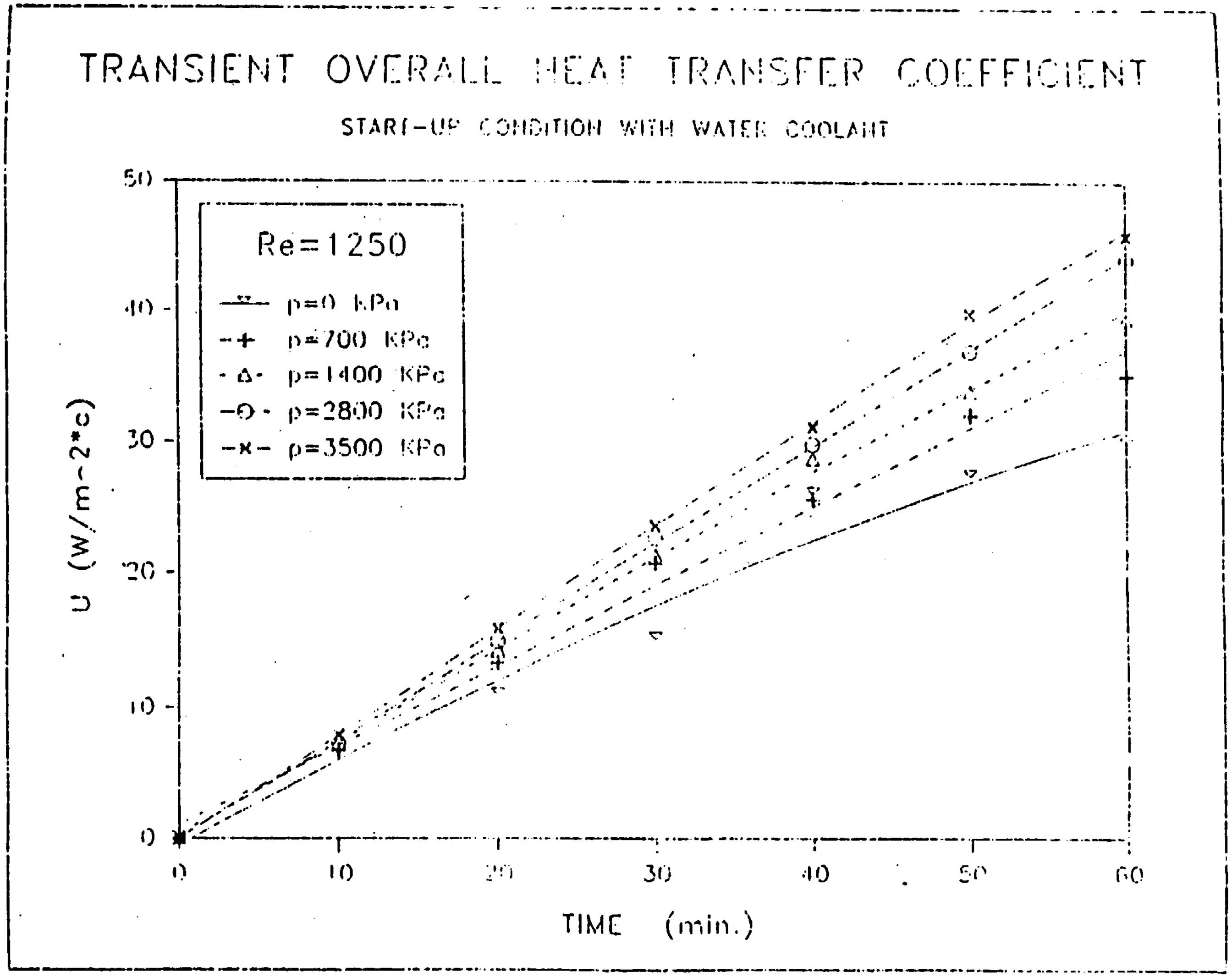


Figure 23. Experimental Transient Overall Heat Transfer Coefficient (Start-Up Condition with Water Coolant Re = 1250).

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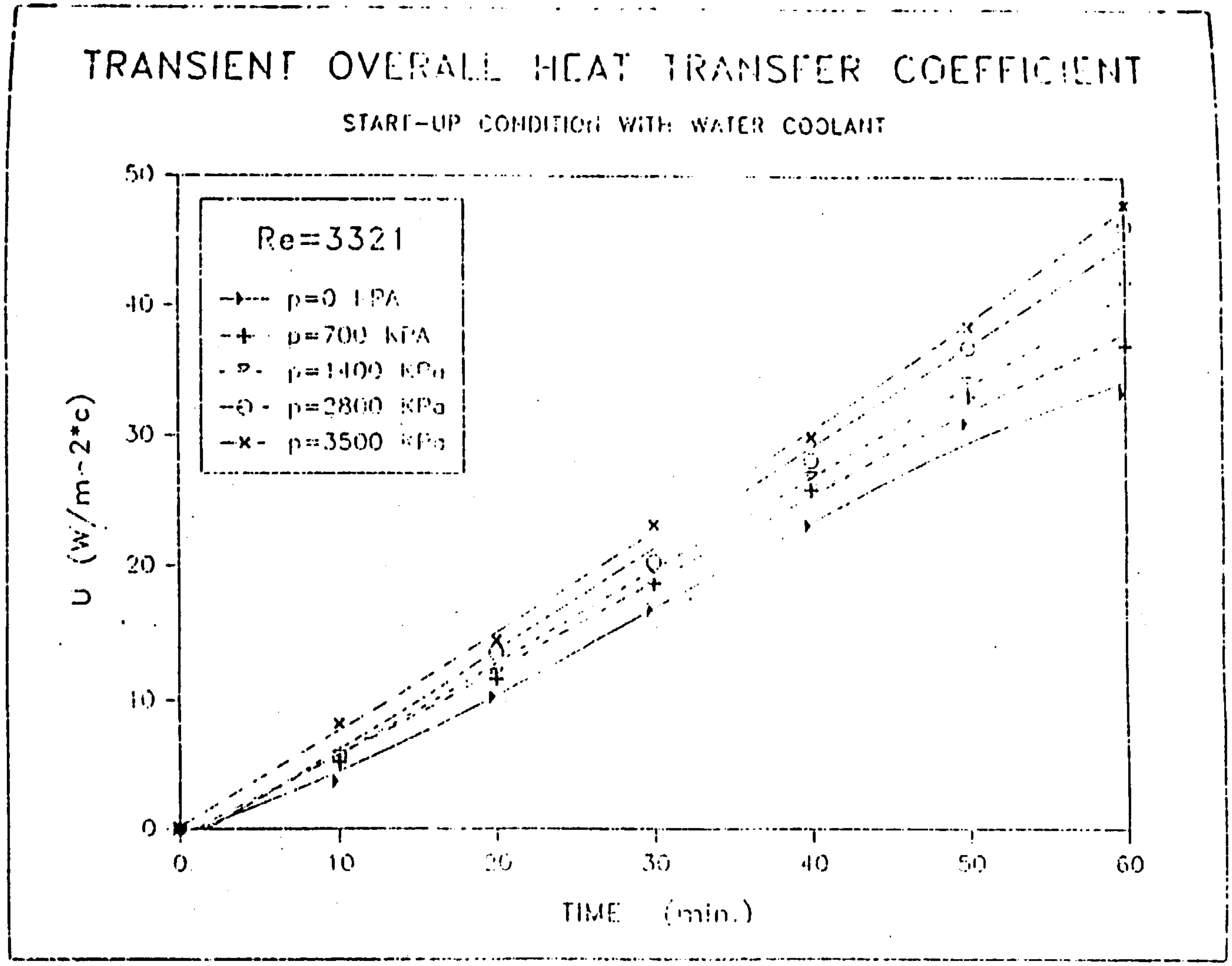


Figure 24. Experimental Transient Overall Heat Transfer Coefficient (Start-Up Condition with Water Coolant Re = 3321).

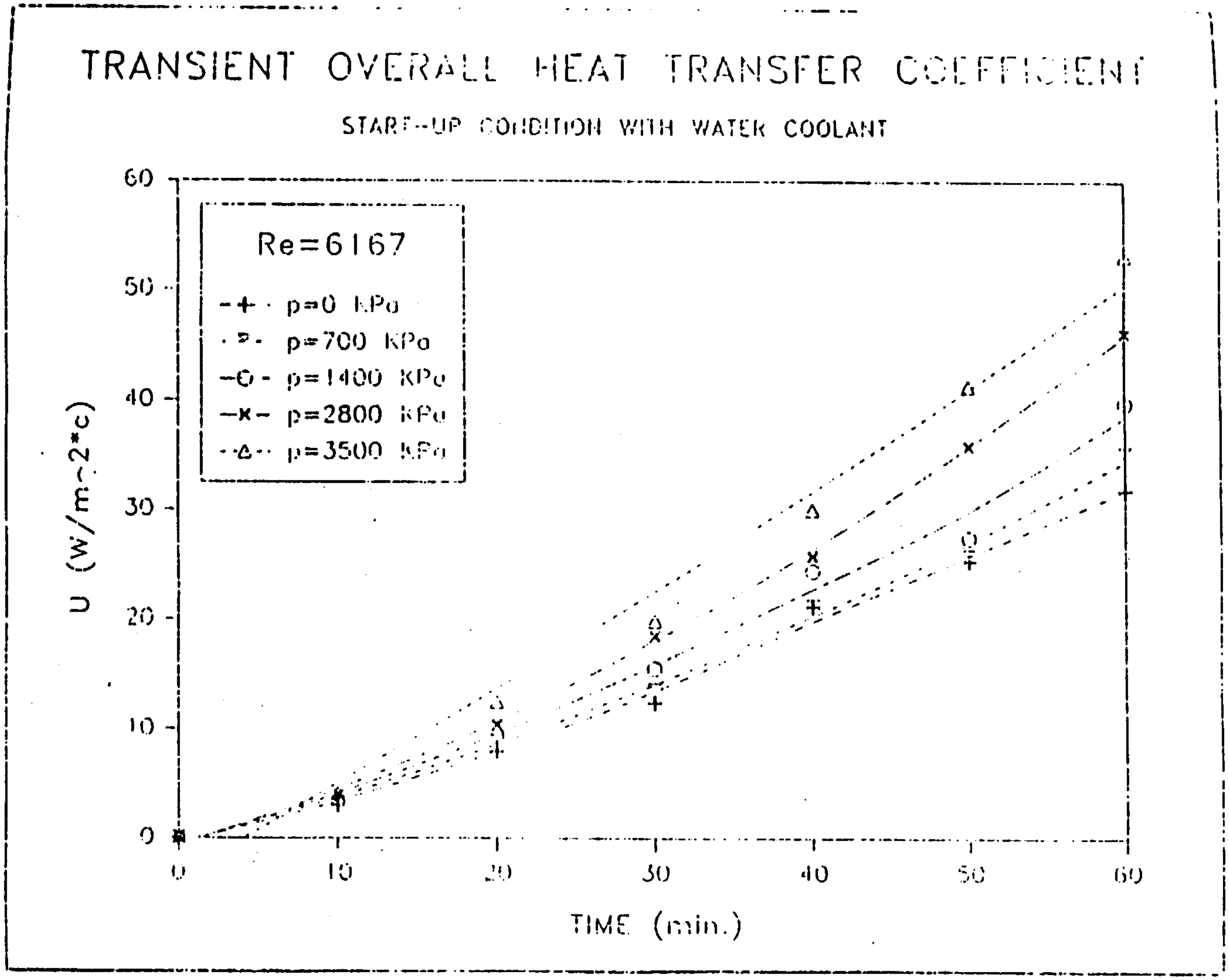


Figure 25. Experimental Transient Overall Heat Transfer Coefficient (Start-Up Condition with Water Coolant Re = 6167).

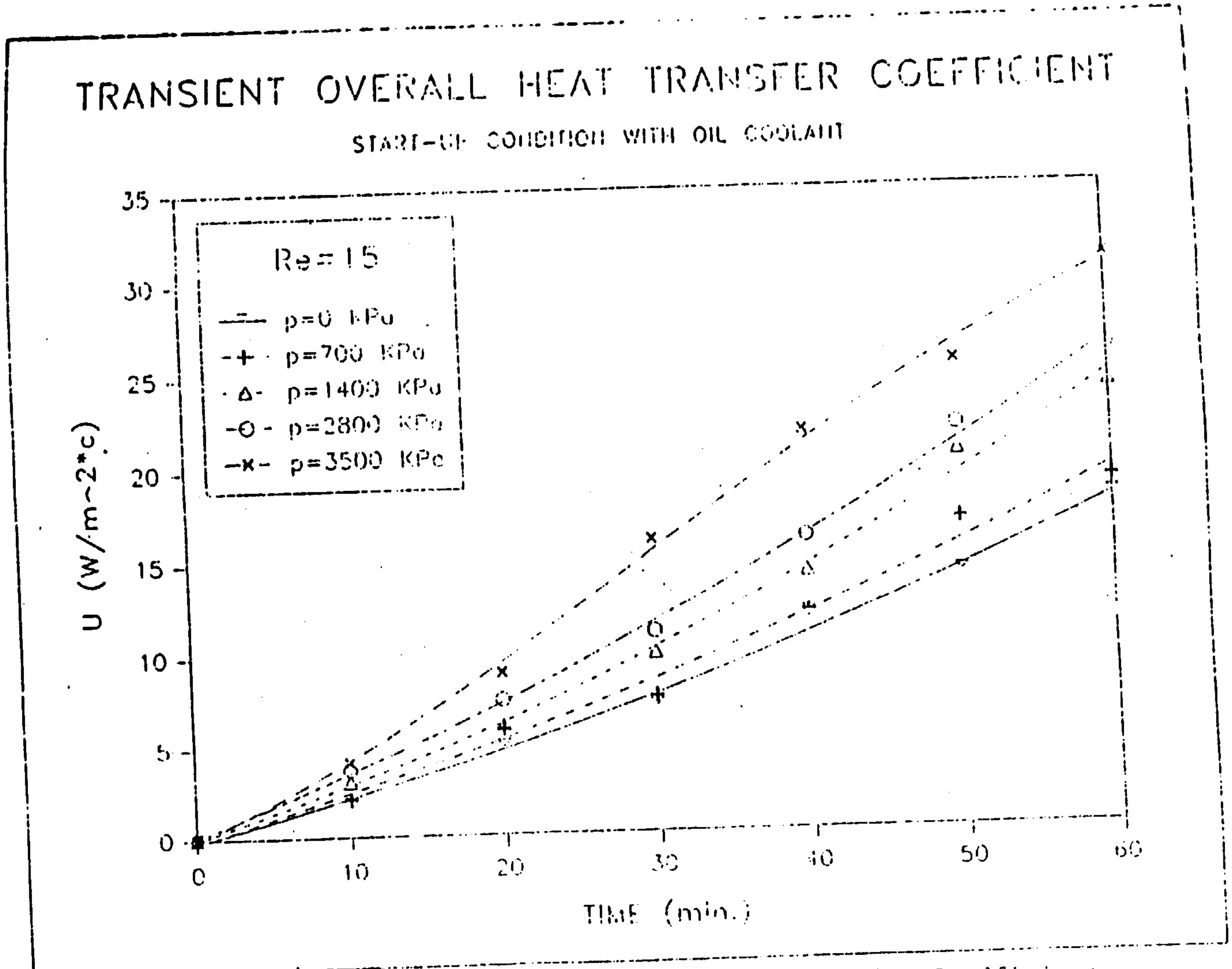

Figure 26. Experimental Transient Overall Heat Transfer Coefficient (Start-Up Condition with Oil Coolant Re = 15).

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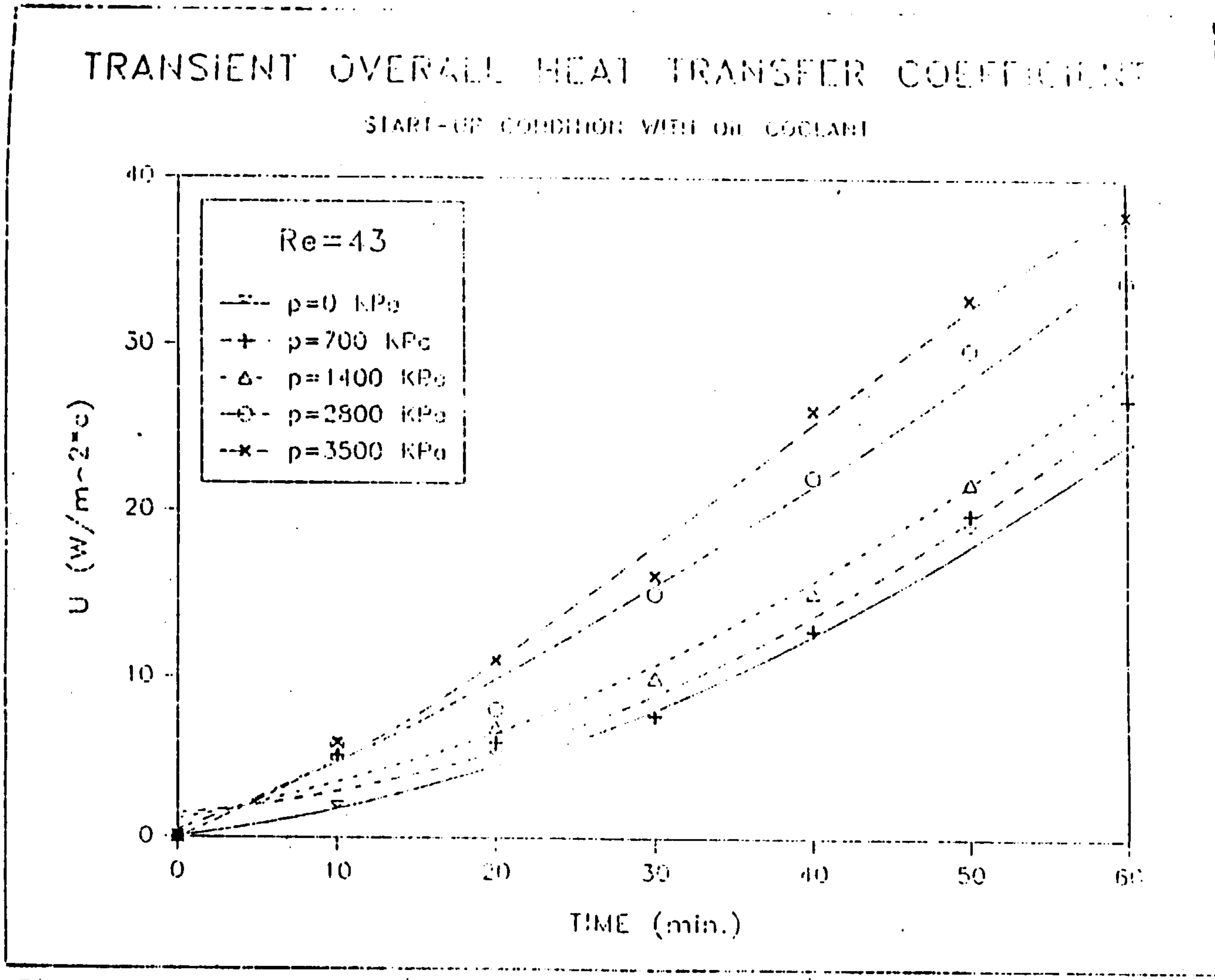


Figure 27. Experimental Transient Overall Heat Transfer Coefficient (Start-Up Condition with Oil Coolant Re = 43).

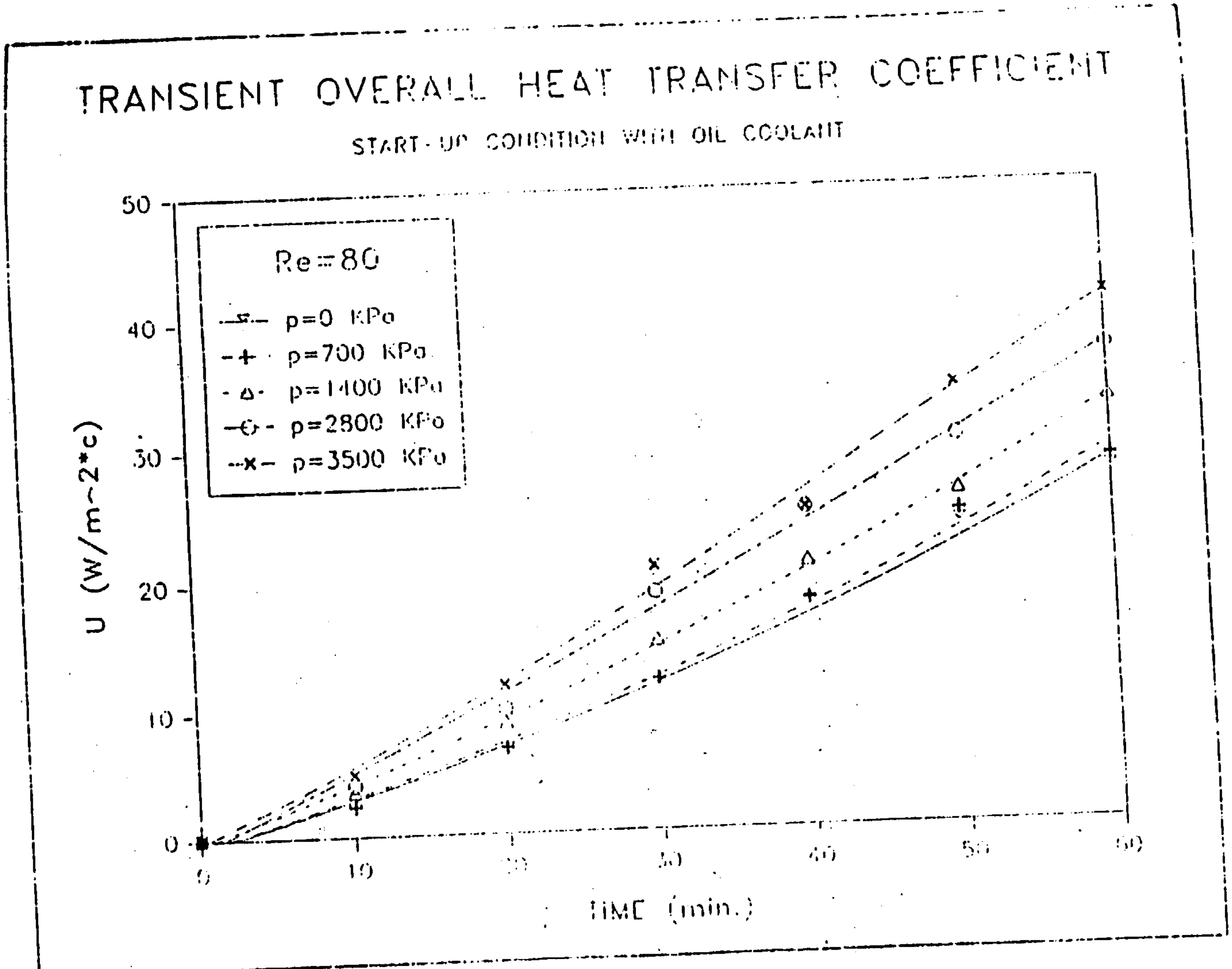


Figure 28. Experimental Transient Overall Heat Transfer Coefficient (Start-Up Condition with Oil Coolant Re = 80).

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### 4.2.2 Shut-Down Process

Referring to section (4.1.1 to (4.1.3)) of this Chapter, the values of h(t), Nu(t) and U(t) were determined using the same set of equations as in the previous section using the collected experimental data from the experimental set-up during a shut-down process.

#### 4.2.2.1 The Variation of the Transient Nusselt Number as a Function of the Cooling System Flow Characteristics

(a) <u>Water Coolant (Re = 1250 to Re = 6167)</u>

Figure 29 summerizes the experimental results of the transient Nusselt number variation during shut-down process for different coolant flow rates.

(b) <u>Oil Coolant (Re=15 to Re=80)</u>

Refer to Figure 30, for the experimental results of the oil Nu number variation during a shut-down process.

#### 4.2.2.2 Measurement of the Transient Thermal Contact Resistance

Figure 31 through 33 exhibits the transient thermal contact resistance measured during part of the shut-down processes and demonstrate the dependence of this thermal resistance mainly on the applied stack pressure for different coolant flow rates.

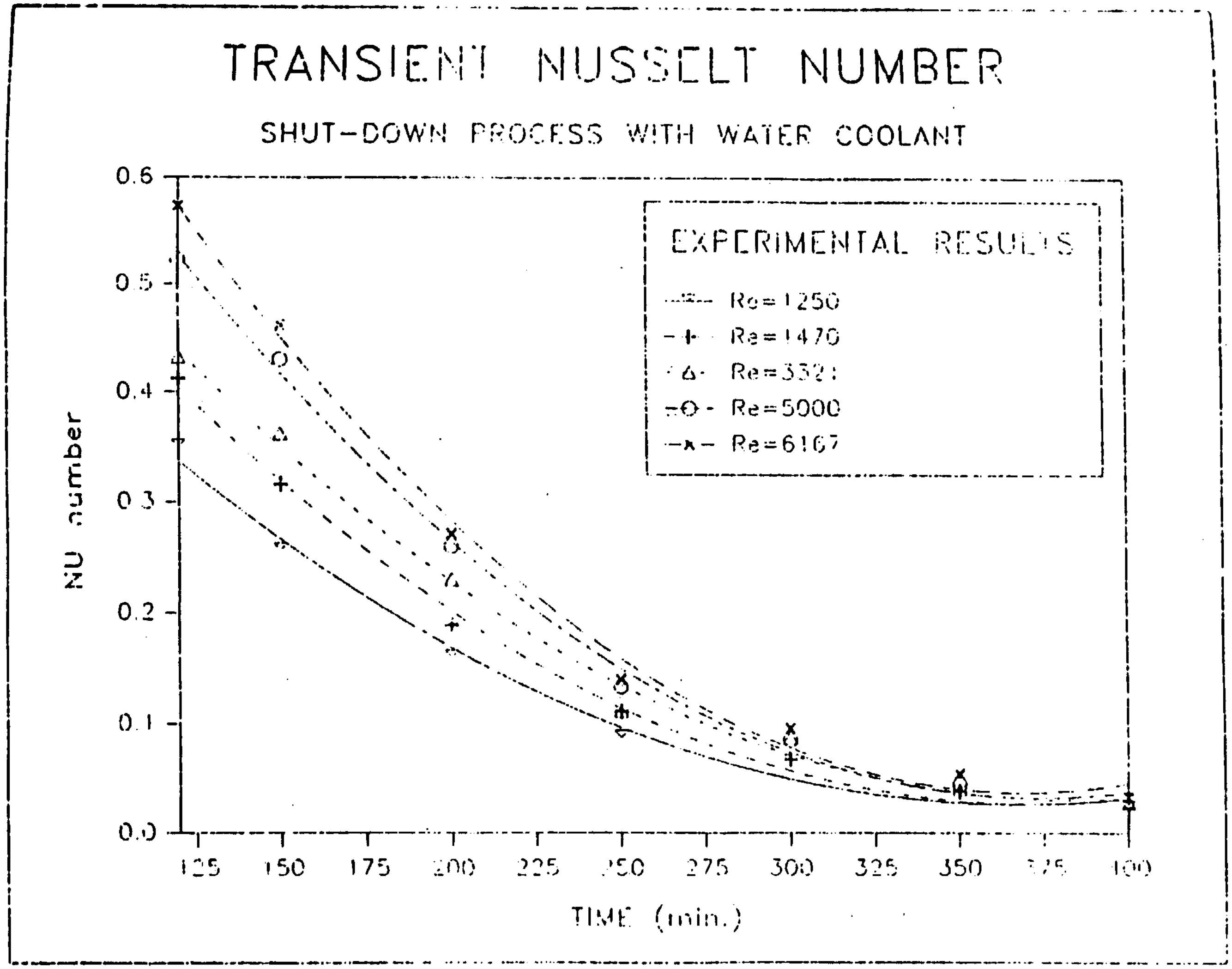


Figure 29. Experimental Transient Nusselt Number (Shut-Down Condition with Water Coolant).

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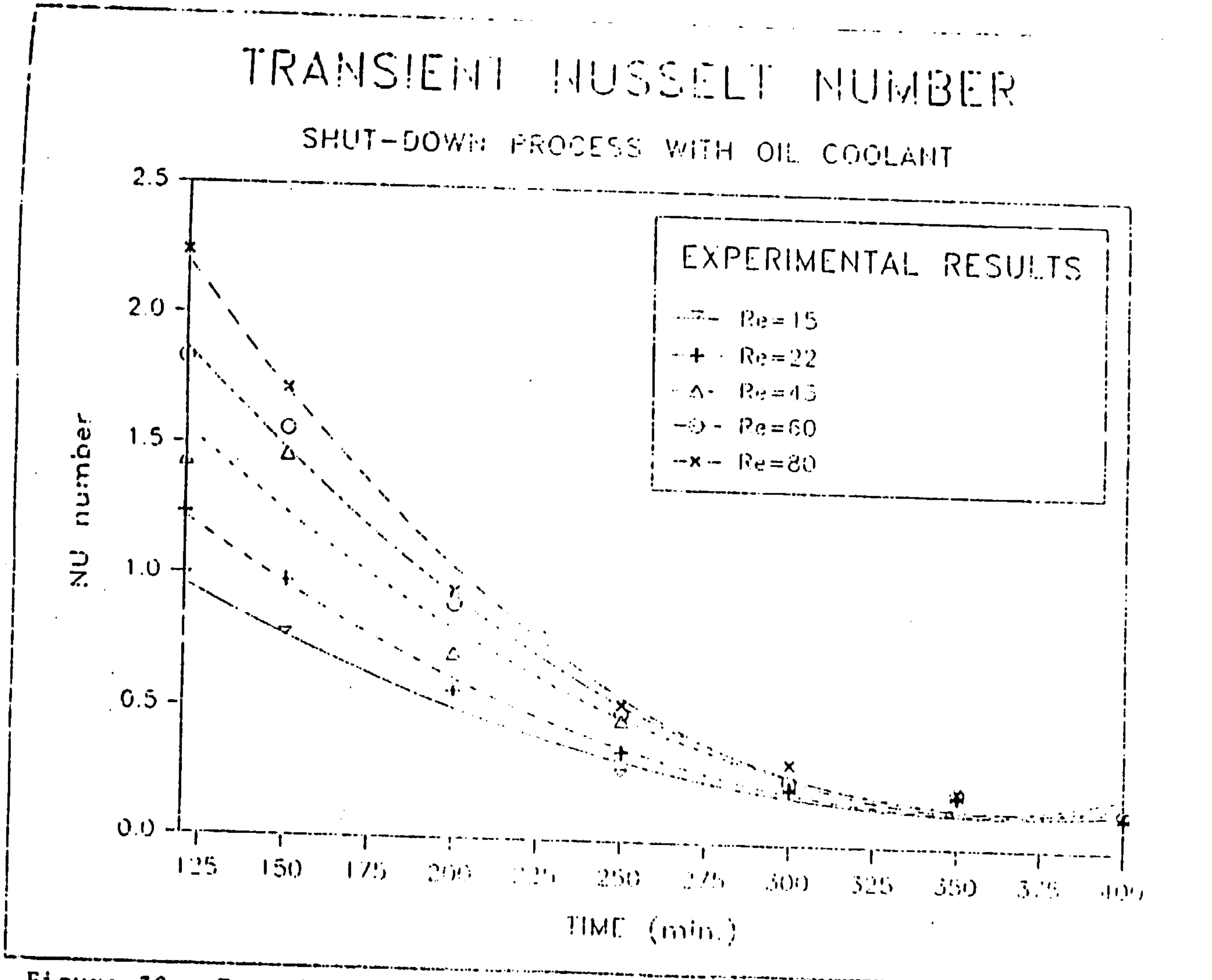


Figure 30. Experimental Transient Nusselt Number (Shut-Down Condition with Oil Coolant).

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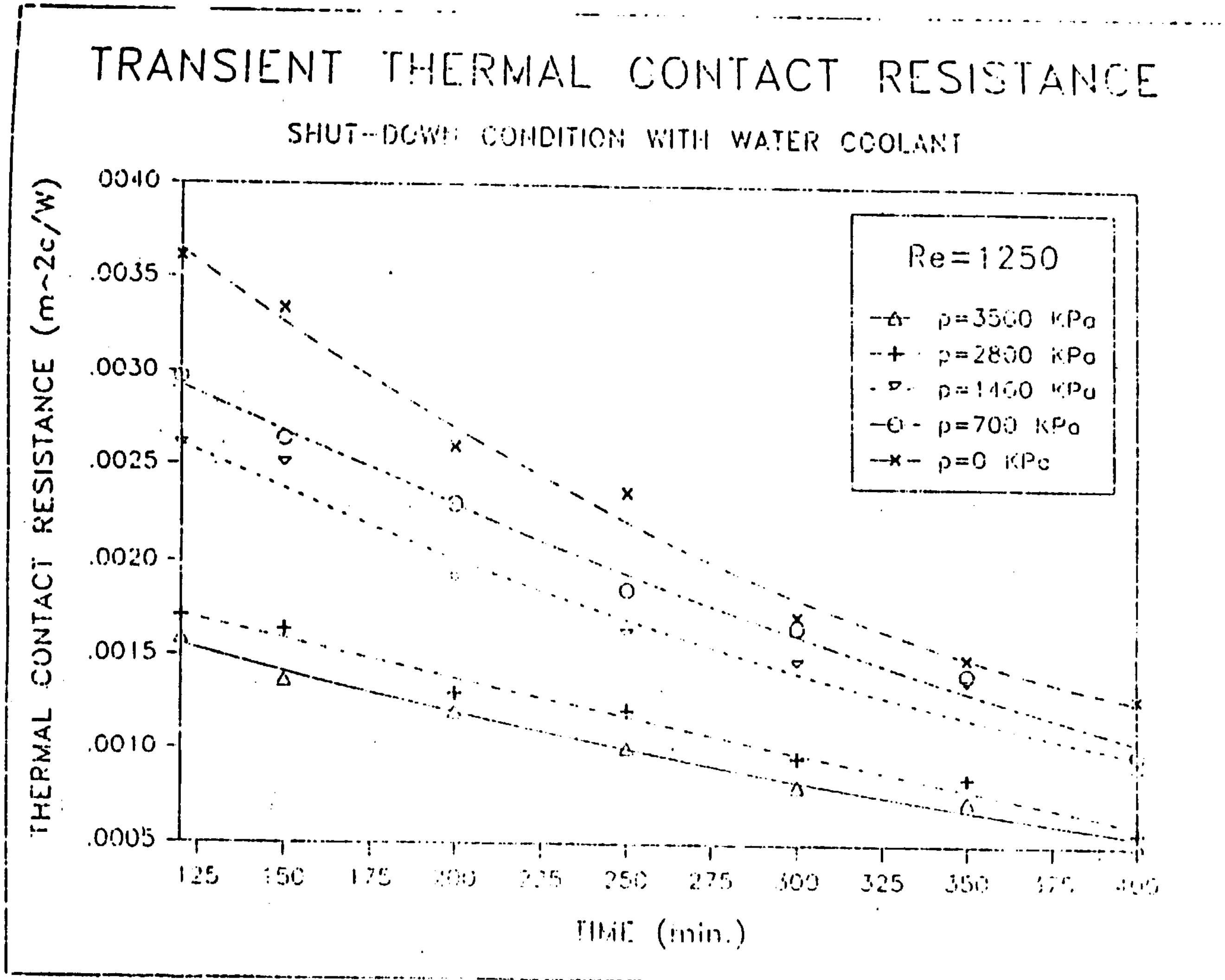


Figure 31. Experimental Transient Thermal Contact Resistance (Shut-Down Condition with Water Coolant, Re = 1250).

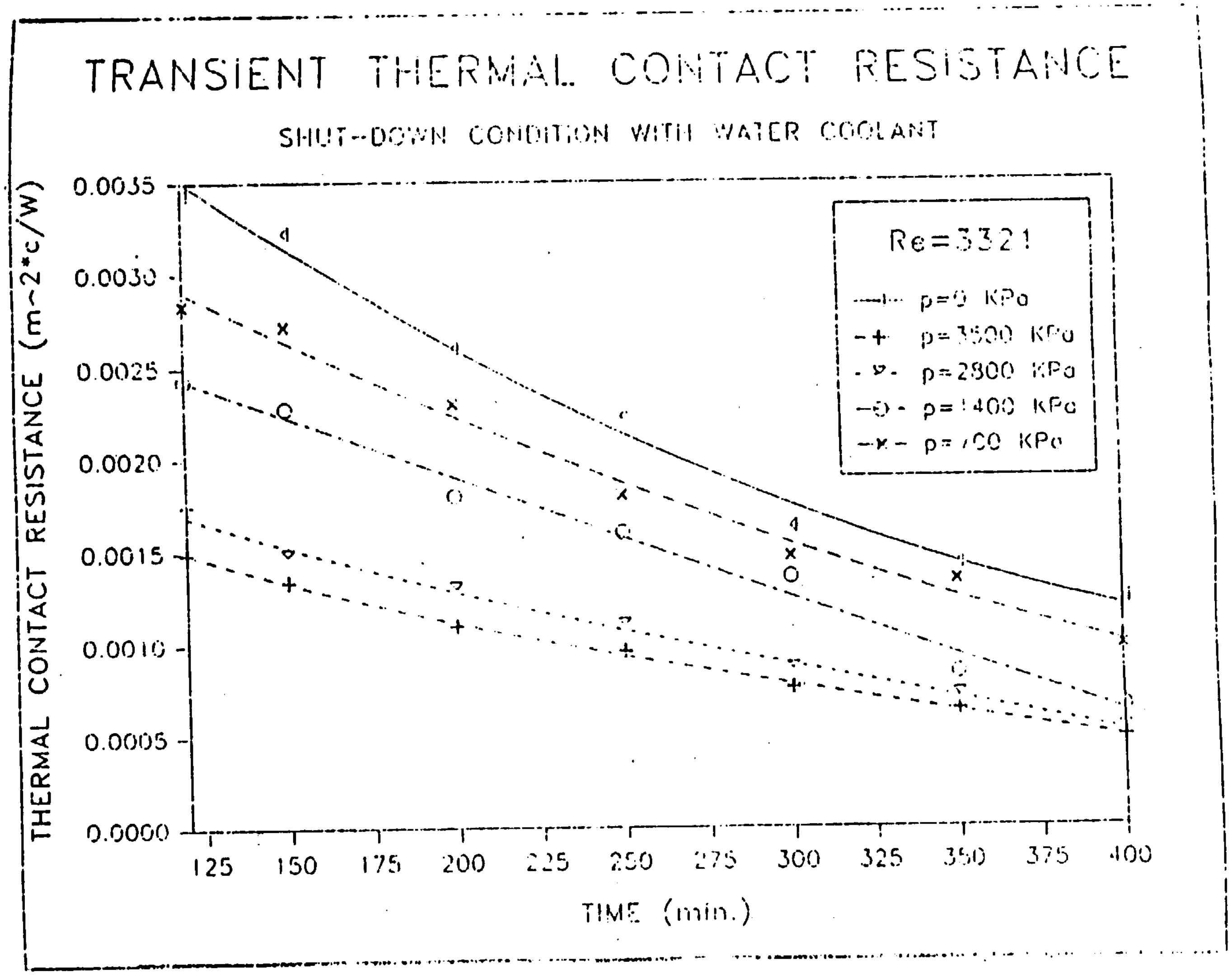


Figure 32. Experimental Transient Thermal Contact Resistance (Shut-Down Condition with Water Coolant, Re = 3321).

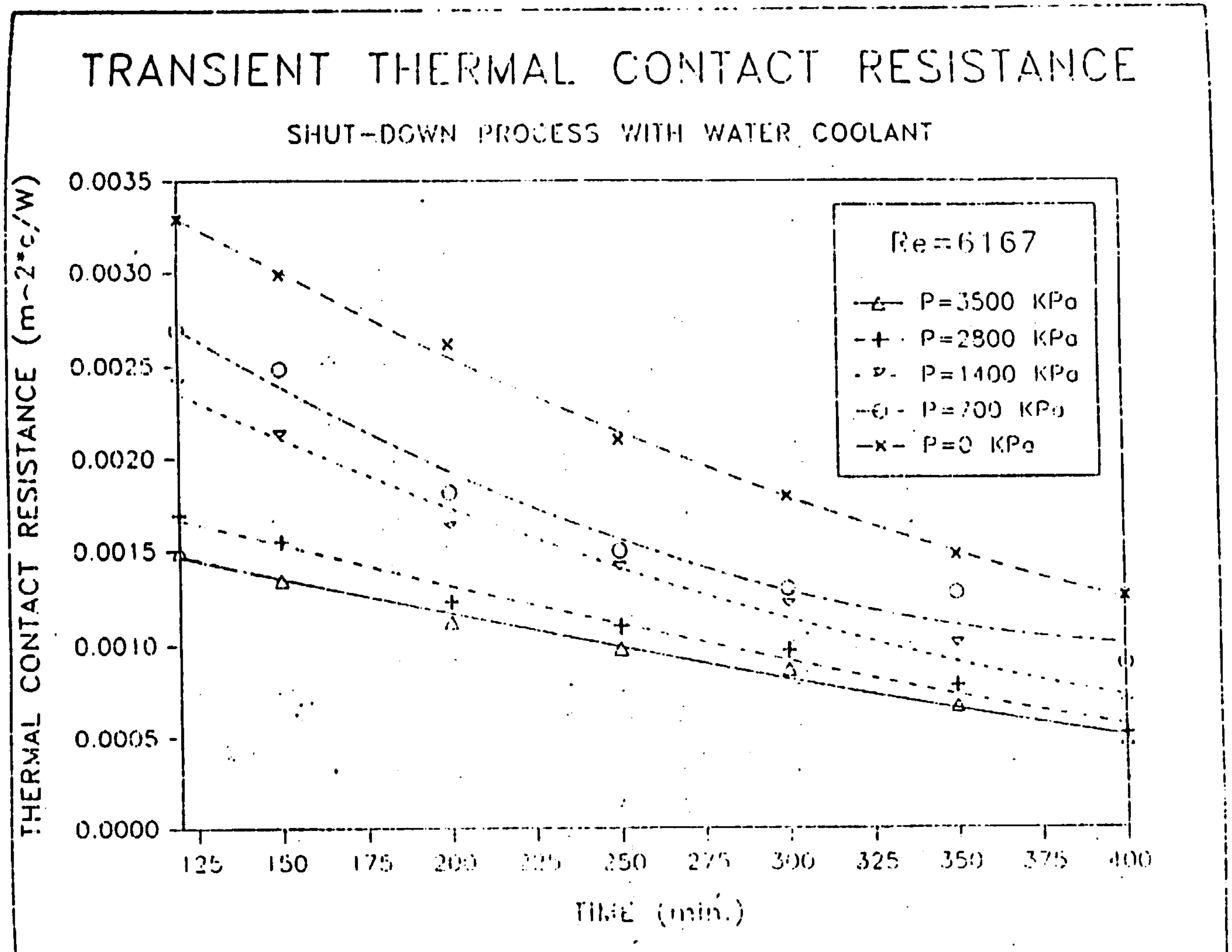


Figure 33. Experimental Transient Thermal Contact Resistance (Shut-Down Condition with Water Coolant, Re = 6167).

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#### 4.2.2.3 The Effect of the Stack Clamping Pressure and the Cooling System Flow Characteristics on the Experimental Transient Overall Heat Transfer Coefficient

(a) Water Coolant (Re = 1250 to RE = 6167)

Figure 34 through Figure 36 shows the variation of the transient overall heat transfer coefficient as a function of the stack clamping pressure and Reynolds number during fifteen complete shut-down processes. During each process the fuel cell model was monitored up to 360 minutes starting at a steady state to accumulate the required experimental data.

(b) Oil Coolant (Re=15 to Re=80)

Refer to Figure 37 through Figure 39 for a summary of the experimental results when oil coolent is used during a shut-down process.

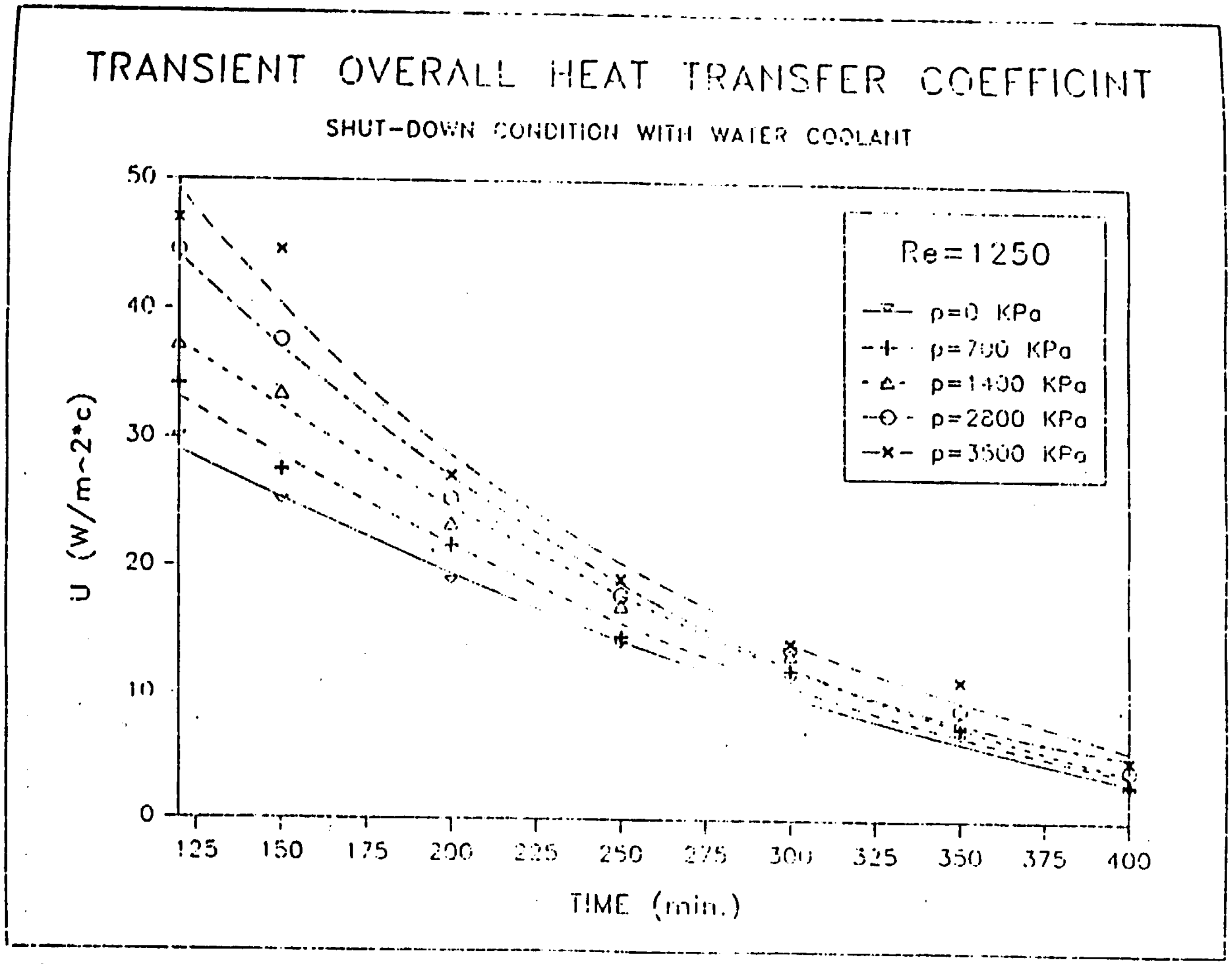


Figure 34. Experimental Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Water Coolant, Re = 1250).

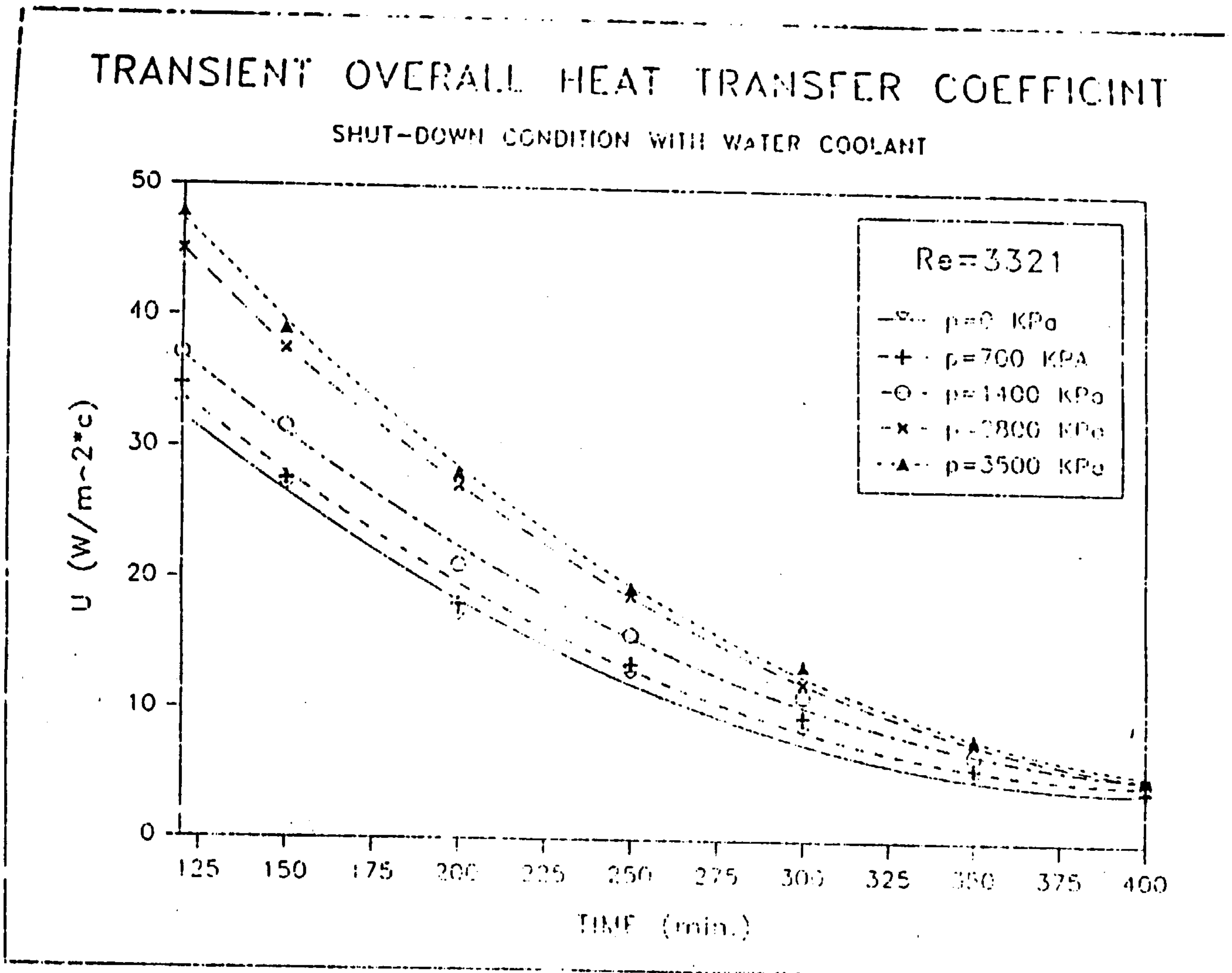


Figure 35. Experimental Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Water Coolant, Re = 3321).

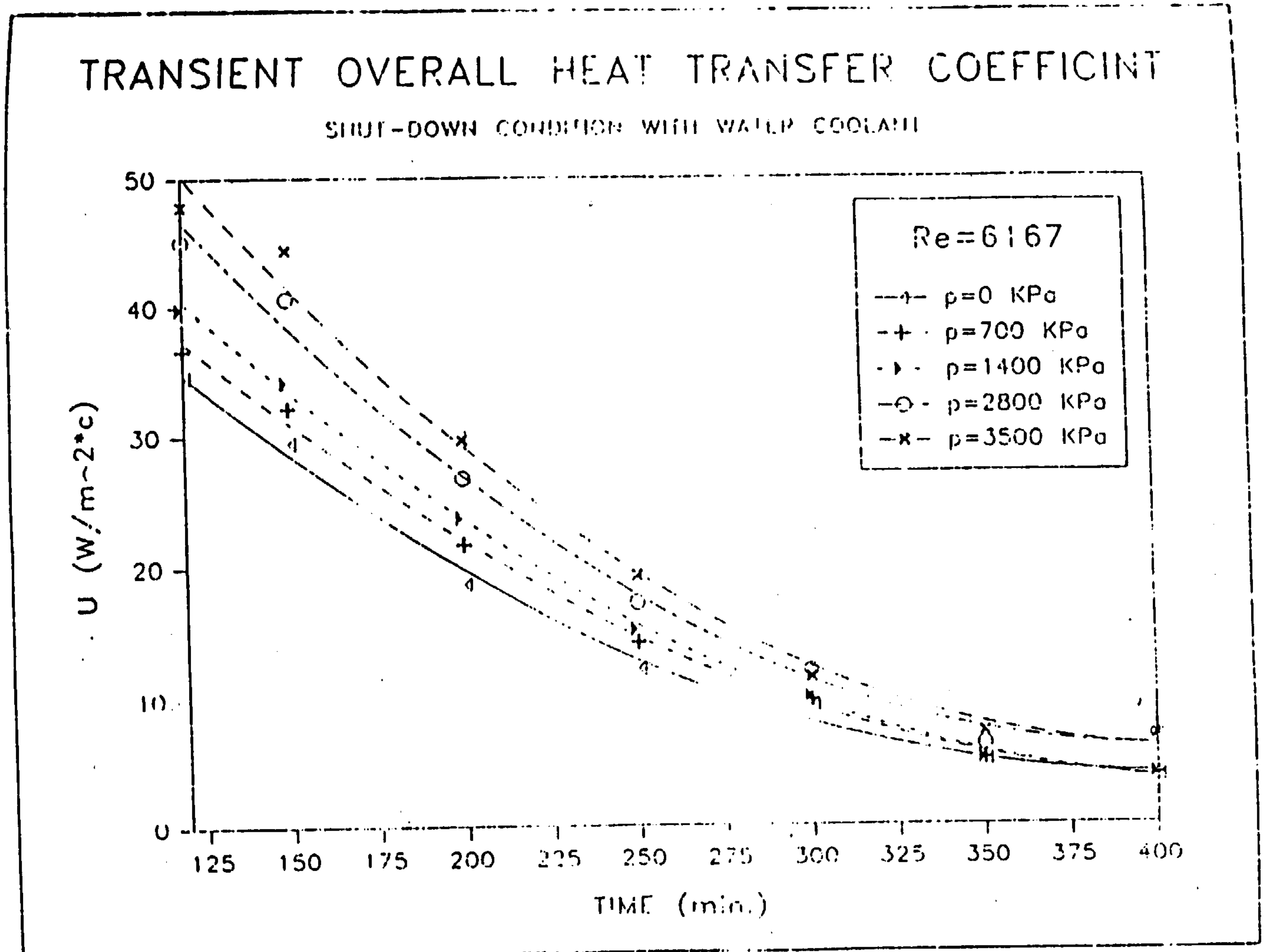


Figure 36. Experimental Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Water Coolant, Re = 6167).

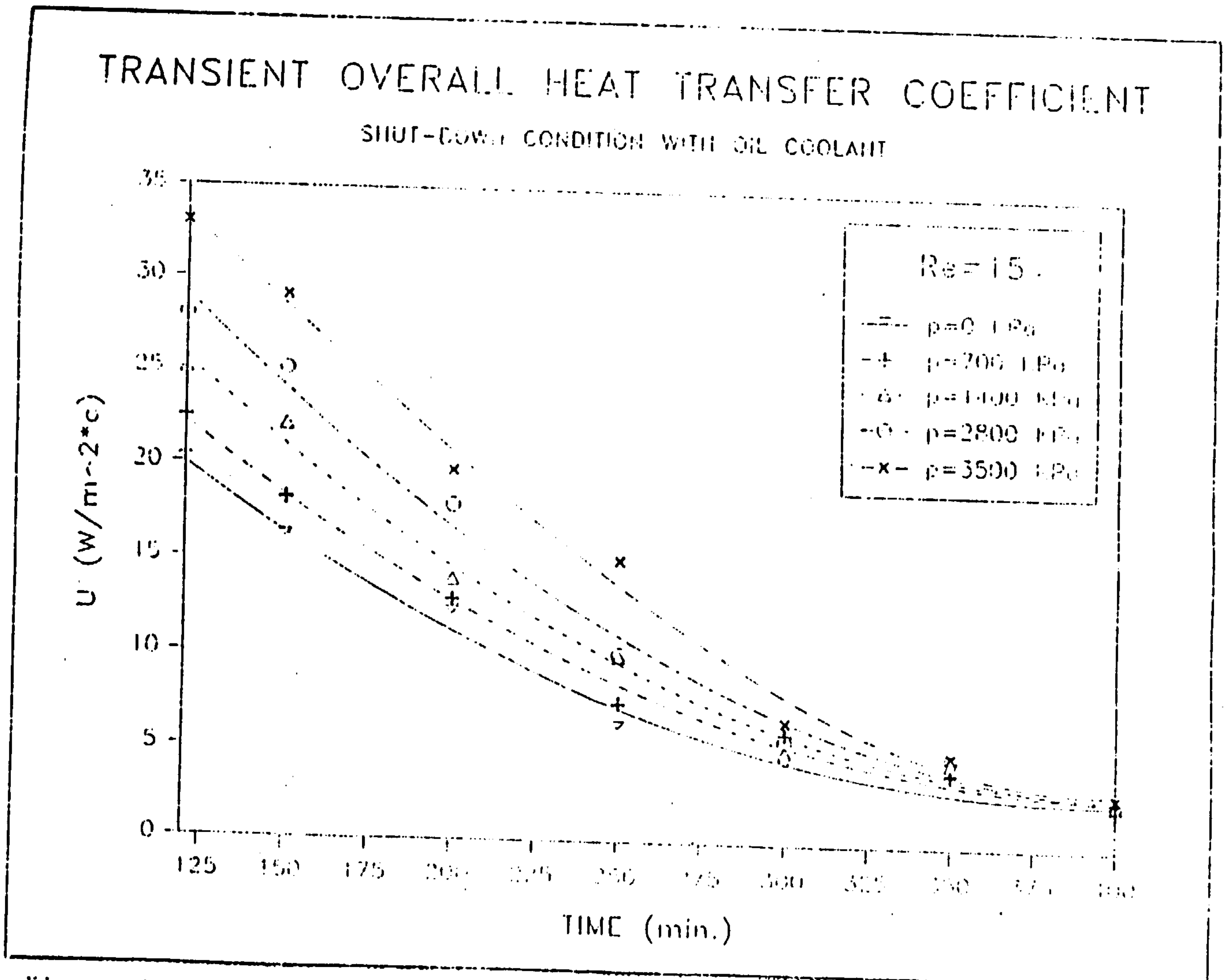


Figure 37. Experimental Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Oil Coolant, Re = 15).

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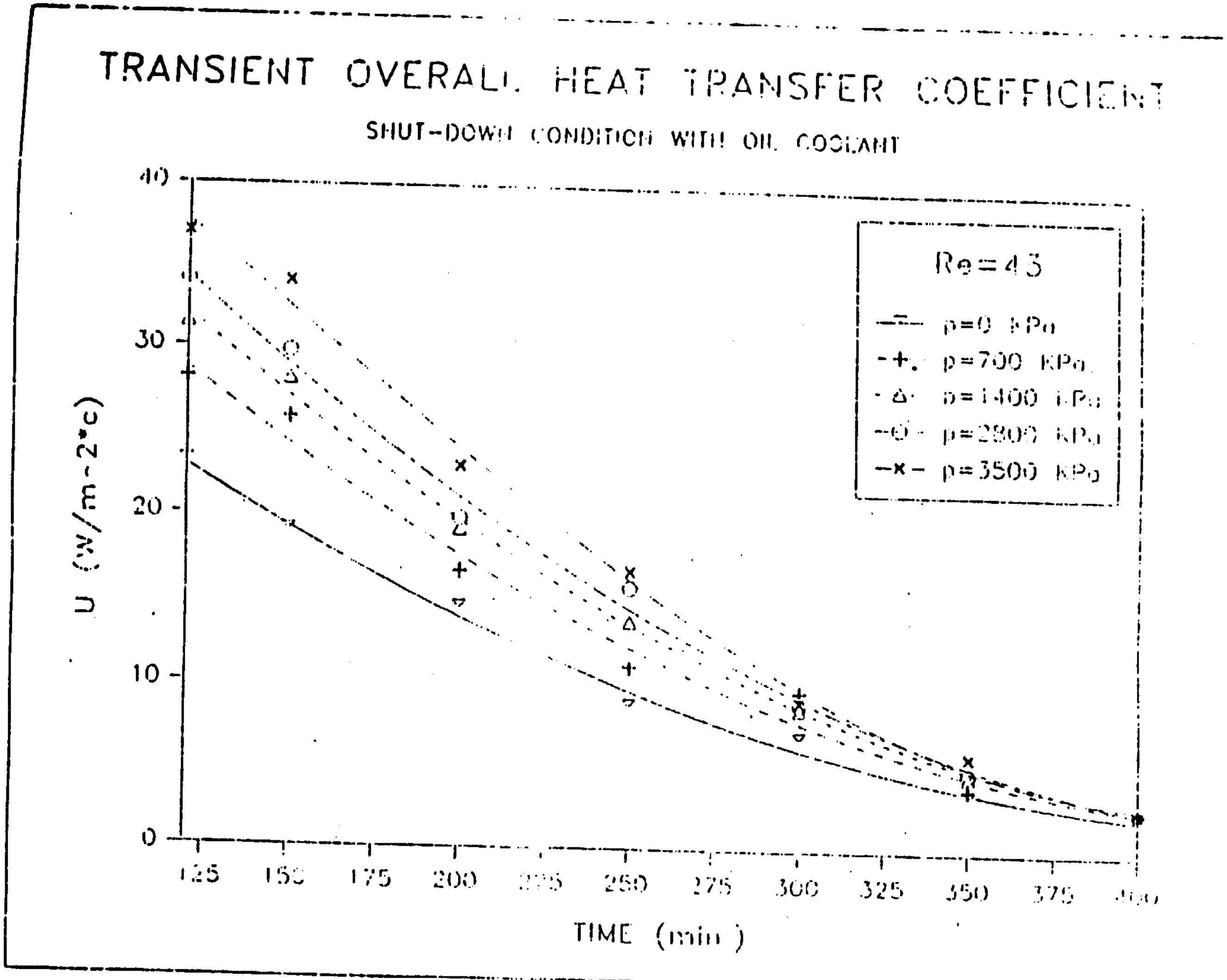


Figure 38. Experimental Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Oil Coolant, Re = 43).

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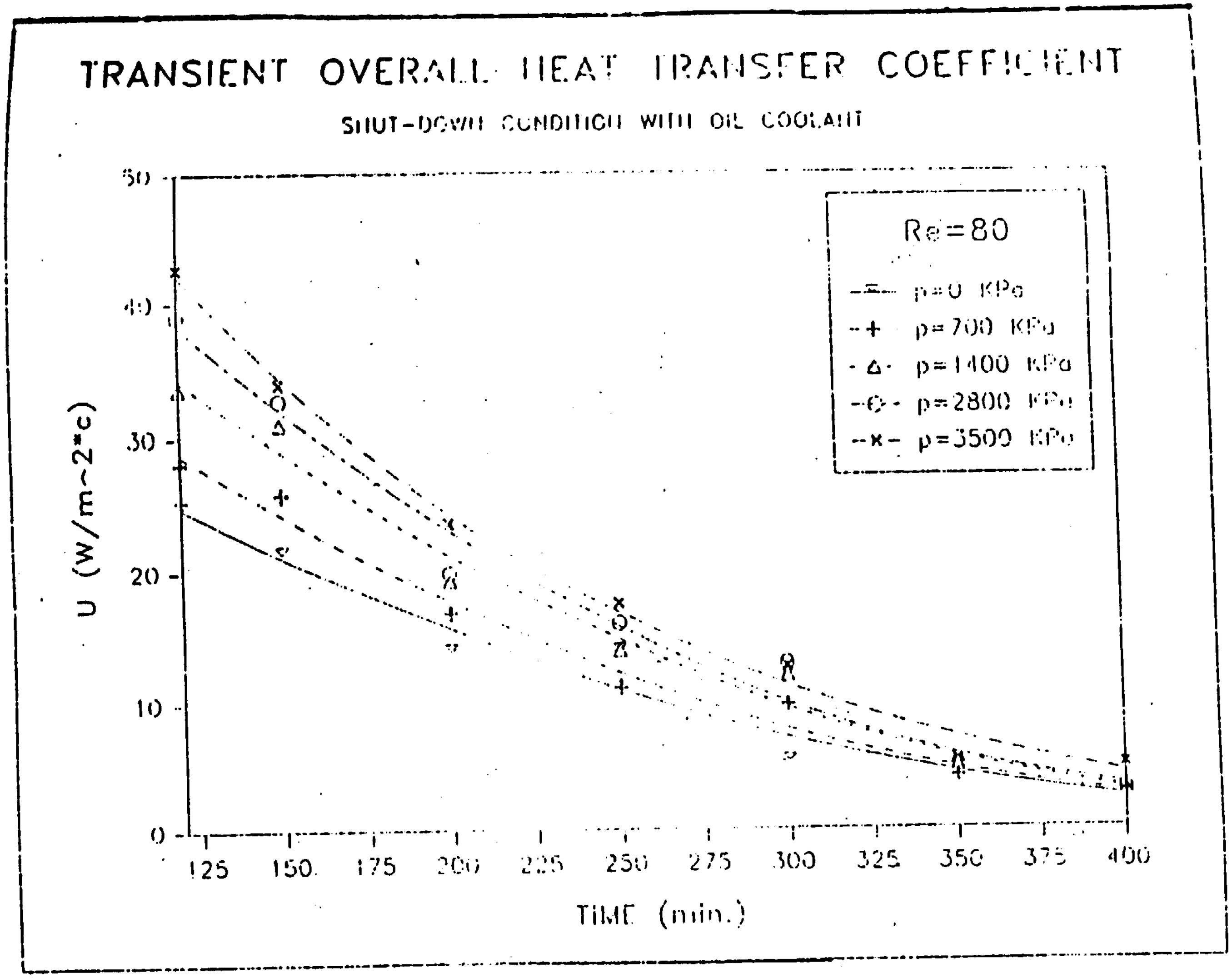


Figure 39. Experimental Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Oil Coolant, Re = 80).

### 4.3 Developed Experimental Correlations

In order to describe the transient performance of fuel-cell, a mathematical expression that interrelates the cell convection heat transfer coefficient, overall heat transfer coefficient and Nusselt number should be developed. Mathematical correlations with an exponential function of time was found to be the most suitable method to achieve this important research objective. This technique allows the establishment of the relationships between the effective parameters and also will exhibit the sensitivity of the transient function to the variation of every independent variable such as pressure and Re number.

A computer program to calculate the convective heat transfer coefficient, the overall heat transfer coefficient, Nusselt number, thermal contact resistance and the effective temperature drop was developed to simulate the change of those parameters during the transient process. The Matlab and the Picquick softwares at the VAX center of Cleveland State University were utilized to employee the curve fitting needed, linear, polynomial, exponential, flexible, and the other algorithms. Also those two softwares were used to plot the generated results.

The transient mathematical correlations that represent the convection heat transfer coefficient and the Nusselt number were found to be a function of the following:

(1) Reynolds Number (flow condition)

(2) Prandlt Number (working fluid property)

(3) Time intervals and the designed operation conditions that reflects the effect of operation conditions on the cell plate surface temperature.

#### 4.3.1 Start-Up Process

In this section, mathematical correlations will be developed to describe the variation of the convection heat transfer coefficient, overall heat transfer coefficient and the Nusselt number during a start-up process as a function of the flow characteristics. Also the effect of the stack pressure should be demonstrated by the overall heat transfer coefficient.

##### 4.3.1.1 Transient Convection Heat Transfer Coefficient and Transient Nusselt Number

For the start-up operation condition the h(t) and Nu(t) correlations can be written as follows:

$$h(t) = \left[A_1 * F_1(Re,Pr) * e^{\lambda_1 t} - B_1 * G_1(Re,Pr)\right] e^{\alpha_1 O} \tag{14}$$

and

$$Nu(t) = \left[A_2 * F_2(Re,Pr) e^{\lambda_2 \cdot t} - B_2 * G_2(Re,Pr)\right] e^{\alpha_2 O} \tag{15}$$

where

$A_1$ = constant,

$F_1(Pr,Re)$ = function of Re and Pr,

$G_1(Pr,Re)$ = function of Re, Pr, and initial operation conditions,

$\lambda_1$ = time constant,

O = operations condition parameter,

$\alpha_1$ = operation condition constant,

$B_1$ = constant,

$A_2$ = constant

$F_2(Pr,Re)$ = function of Re, and Pr,

$G_2(Pr,Re)$ = function of Re,Pr, and initial operation condition,

$\lambda_2$ = time constant,

$\alpha_2$ = operation condition constant,

$\beta_2$ = constant.

It should be noted that $F_1$, $G_1$, $F_2$, and $G_2$ are not functions of time but actually are functions of the flow, working fluid properties and design criteria. The developed experimental correlations for both considered working fluids can then be written using equations (14) and is as follows:

(a) <u>Water Coolant (Re = 1250 to Re = 6167)</u>

$$h(t) = 31.088\ (Re^{0.05779})(e^{0.00953t})(Pr^{0.01433})(e^{0.000124o}) - 31.088\ (Re^{0.05779})(Pr^{0.01433})(e^{0.000124o}) \quad (15)$$

$$Nu(t) = 0.3259\ (Re^{0.05632})(e^{0.008219t})(Pr^{0.0385})(e^{0.000123o}) - 0.3259\ (Re^{0.05632})(Pr^{0.00385})(e^{0.000123o}) \quad (16)$$

The variation of Nu(t) with different Re number for the considered start-up process are exhibited by Figure 40. Only five Re number results are shown to summarize. It should be noted that $F_1 = G_2$, $A_1 = B_1$, $A_2 = B_2$ and $F_2 = G_2$ and $\alpha_1 o$, $\alpha_2 o$ are correction factors that will allow the correlation to be sensitive to the effect of P on the cell

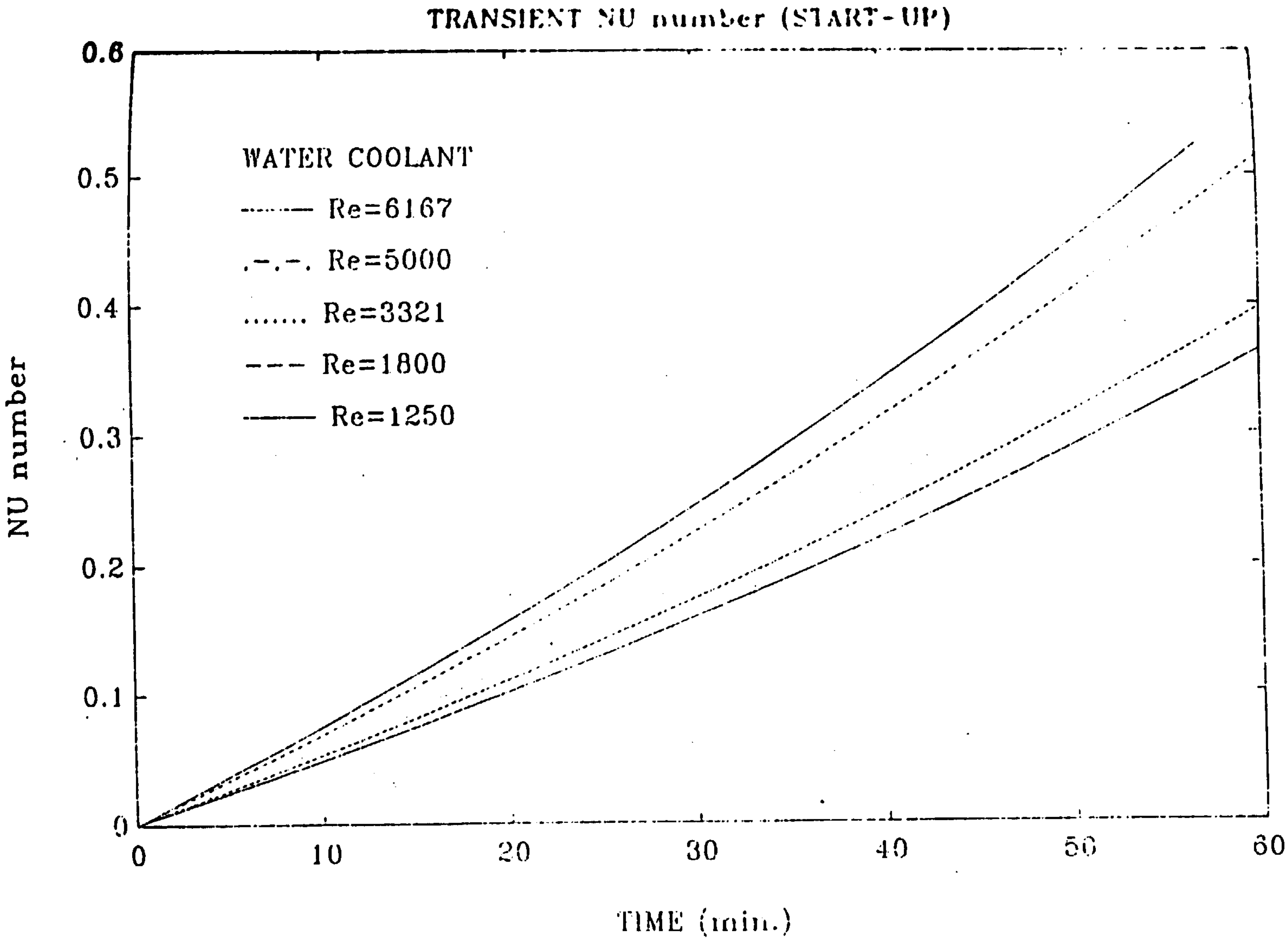


Figure 40. Analytical Transient Nusselt Number (Start-Up Process with Water Coolant).

temperature. The second term of the two equations was used to simulate the initial equation condition of zero heat transfer at t = 0.

(b) <u>Oil Coolant (Re=15 to Re=80)</u>

$$h(t) = 16.088\ (Re^{0.216})\ (e^{0.00961t})\ (Pr^{0.0076})\ (e^{1.356*10-4o})$$
$$-\ 16.088\ (Re^{0.216})\ (Pr^{0.0076})\ (e^{1.356*10-4o}) \qquad (17)$$

$$Nu(t) = 0.7326\ (Re^{0.214})\ (Pr^{0.0039})\ (e^{1.356*10-4o}) \qquad (18)$$

The variation of Nu(t) with different considered cases start-up processes are shown in Figure 41.

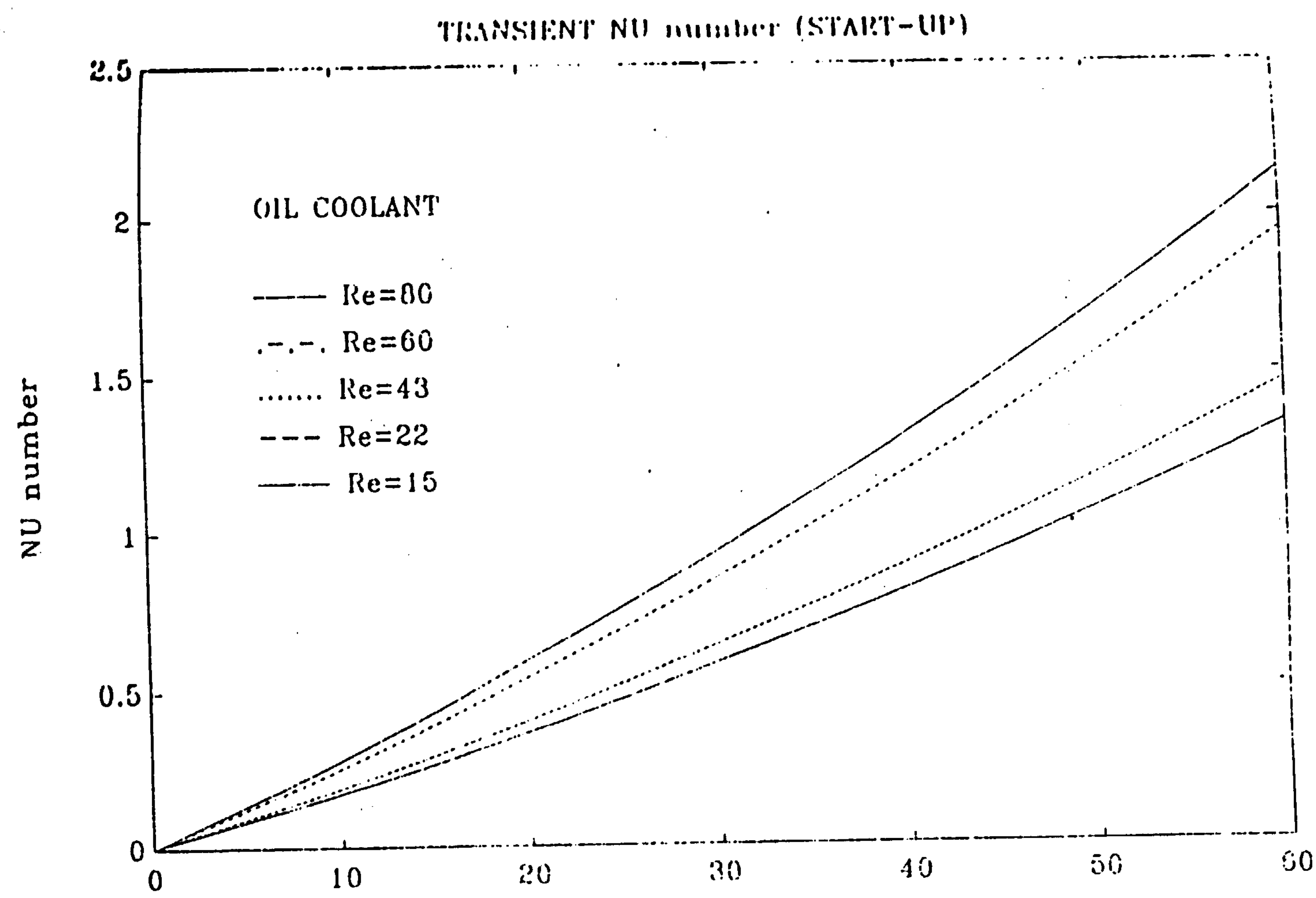


Figure 41. Analytical Transient Nusselt Number (Start-Up Process with Oil Coolant).

### 4.3.1.2 Transient Thermal Contact Resistance and Effective Temperature Drop

The experimental correlations that were developed to simulate the change of the transient thermal contact resistance and the effective temperature drop must demonstrate the effect of time, stack clamping pressure flow characteristics, and the operation condition as concluded from the experimental results. In general, the developed correlations can be formulated as follows:

$$r_c(t) = A_3\left[W_1(p) * e^{\lambda_3 t} - W_2(p)\right]e^{\gamma_1 O} \tag{19}$$

$$\Delta T(t) = \left[(A_4 - W_3(p))e^{\lambda_4 t} - (A_5 - W_4(p))\right]e^{\gamma_2 O} \tag{20}$$

where

$A_3$, $A_4$, $A_5$ = constants,

$W_1(p)$ = function of stack pressure,

$\lambda_3$ = time constant,

$W_2(p)$ = function of stack pressure,

p = stack pressure

$\lambda_4$ = time constant,

$\gamma_1$, $\gamma_2$ = operation condition constants,

$W_3(p)$ = function of stack pressure,

$W_4(p)$ = function of stack pressure.

o = operation condition parameter

It is important to notice that $W_1$, $W_2$, $W_3$ and $W_4$ are not a function of time but a function of the applied stack pressure, therefore, the developed correlation for both

considered working fluids can be written as follows:

(a) <u>Water Coolant (Re = 1250 to Re = 6167)</u>

$$r_c(t) = 0.00357[(e^{-0.000236p})*(e^{0.0114t}) - (e^{-0.000236p})]\ e^{-0.0000179o} \quad (21)$$

$$T(t) = [(7.986 - 0.000959p)e^{0.012t} - (7.986 - 0.000959p)]\ e^{-0.0000116o} \quad (22)$$

The results generated by the above two correlations are shown in Figure 42 to Figure 44 and Figures 48 to 50 respectively, for all the stack pressures applied and for the minimum, average, and maximum volumetric flow rate. It should be noticed that $w_1 = w_2$ and $w_3 = w_4$ for this case and o was found to be directly proportional to the flow rate.

(b) <u>Oil Coolant (Re=15 to Re=80)</u>

$$r_c(t) = 3.61*10^{-3}\ (e^{0.0122t}) * (e^{-2.235*10\text{-}4p}) - (e^{-2.356*10\text{-}4p})]\ e^{-1.796*10\text{-}5o} \quad (23)$$

$$T(t) = [(7.985 - 9.597*10^{-4}p)\ e^{0.0122t} - (7.985 - 9.597*10^{-4}p)]\ e^{-0.0000116o} \quad (24)$$

A summary for the results generated by the above two correlations for the oil coolant case are shown in Figure 45 to Figure 47 and Figures 51 to 53 respectively, for all the stack pressures applied and for the minimum, average, and maximum volumetric flow rate.

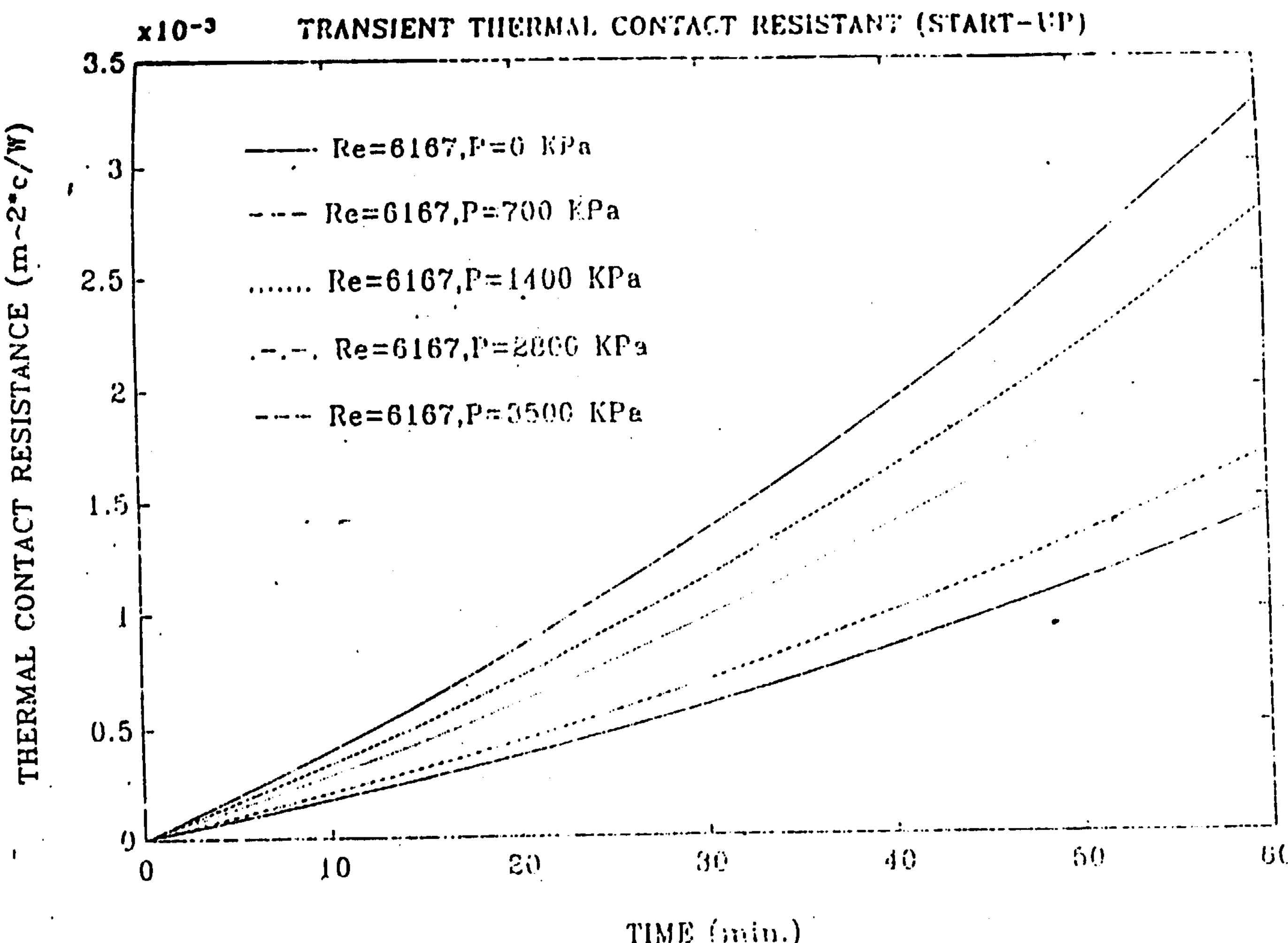


Figure 42. Analytical Transient Thermal Contact Resistance (Start-Up Condition with Water Coolant, Re = 1250).

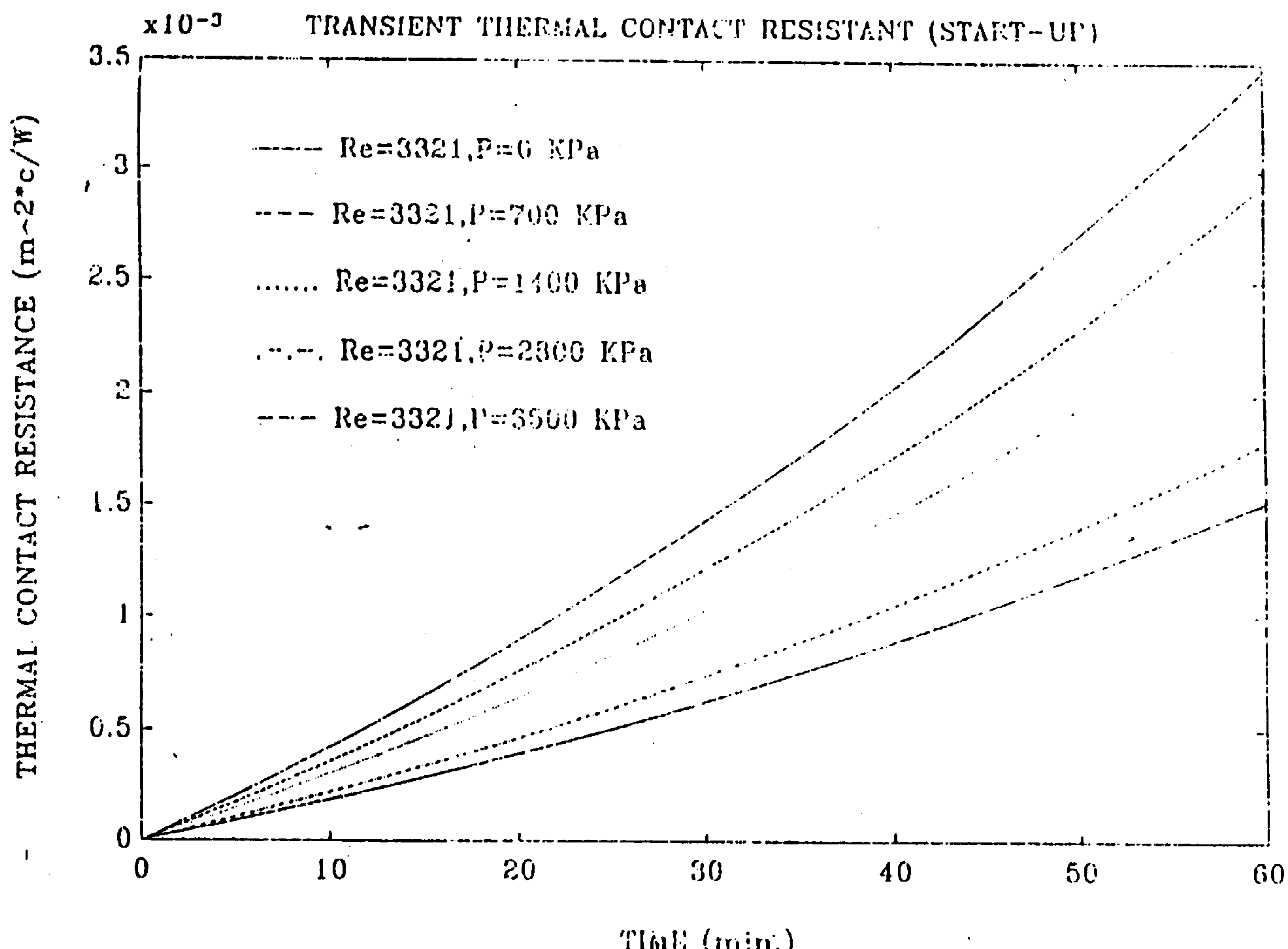


Figure 43. Analytical Transient Thermal Contact Resistance (Start-Up Condition with Water Coolant, Re = 3321).

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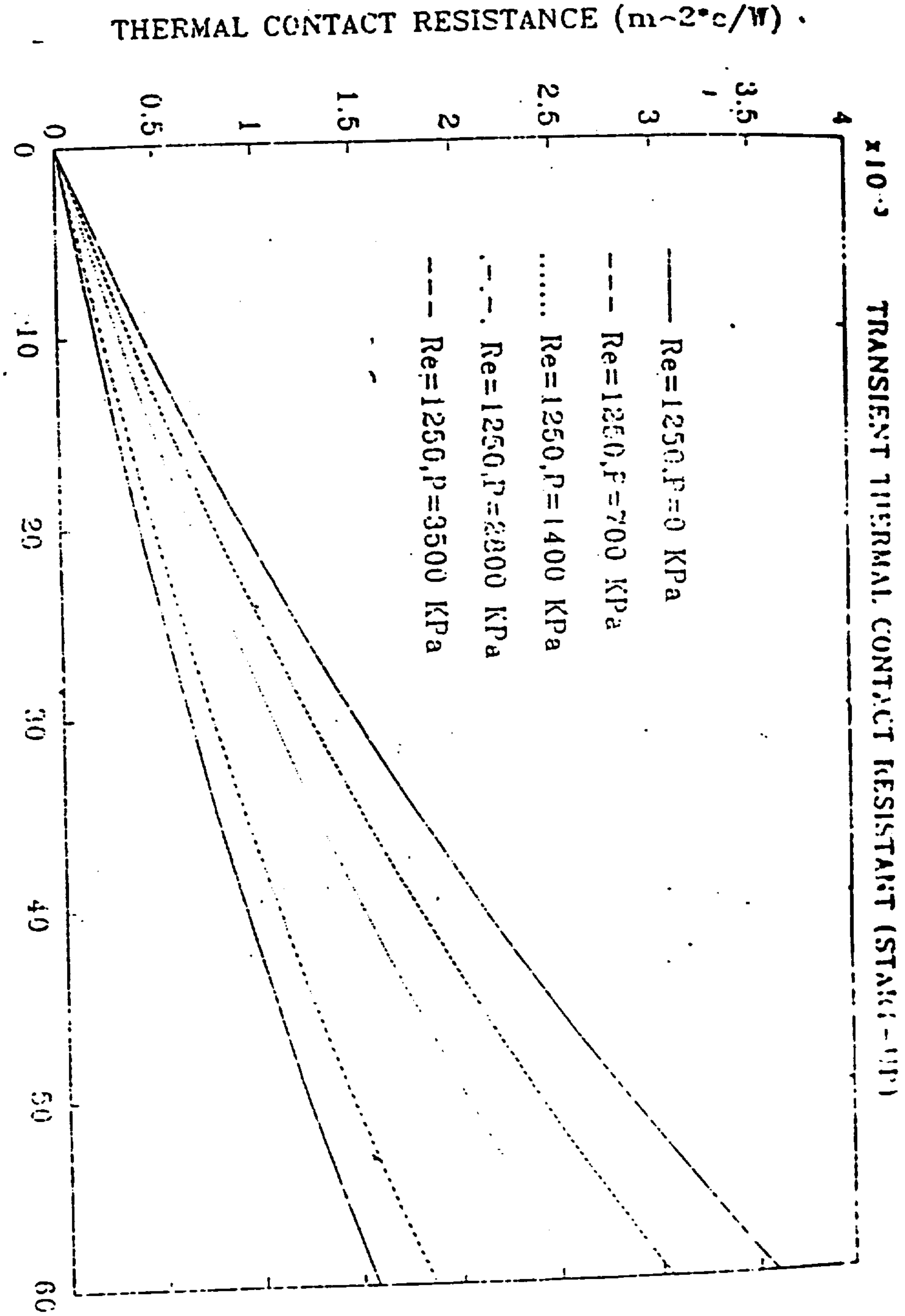


Figure 44. Analytical Transient Thermal Contact Resistance (Start-Up Condition with Water Coolant, Re = 3167).

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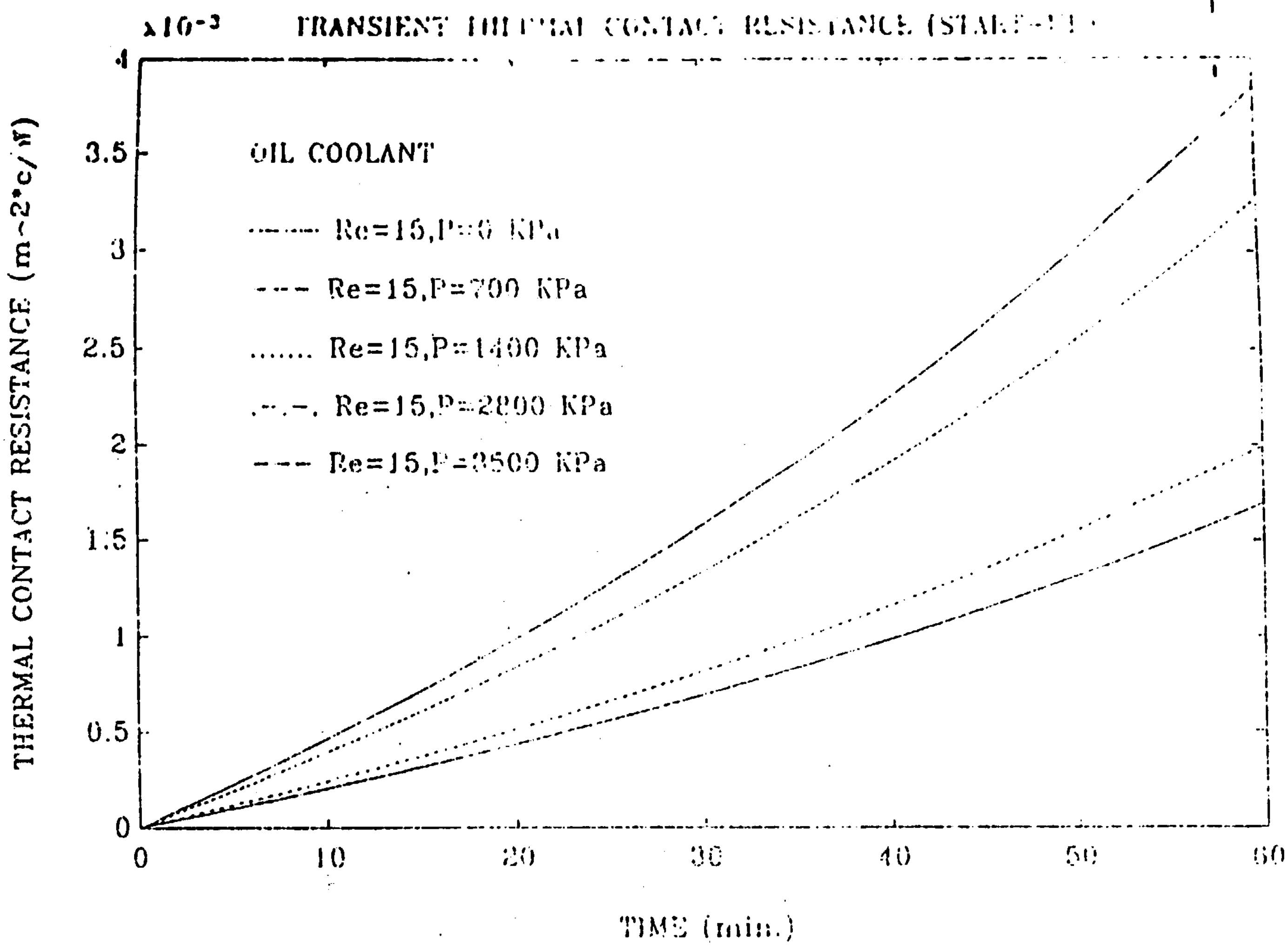


Figure 45. Analytical Transient Thermal Contact Resistance (Start-Up Condition with Oil Coolant, Re = 15).

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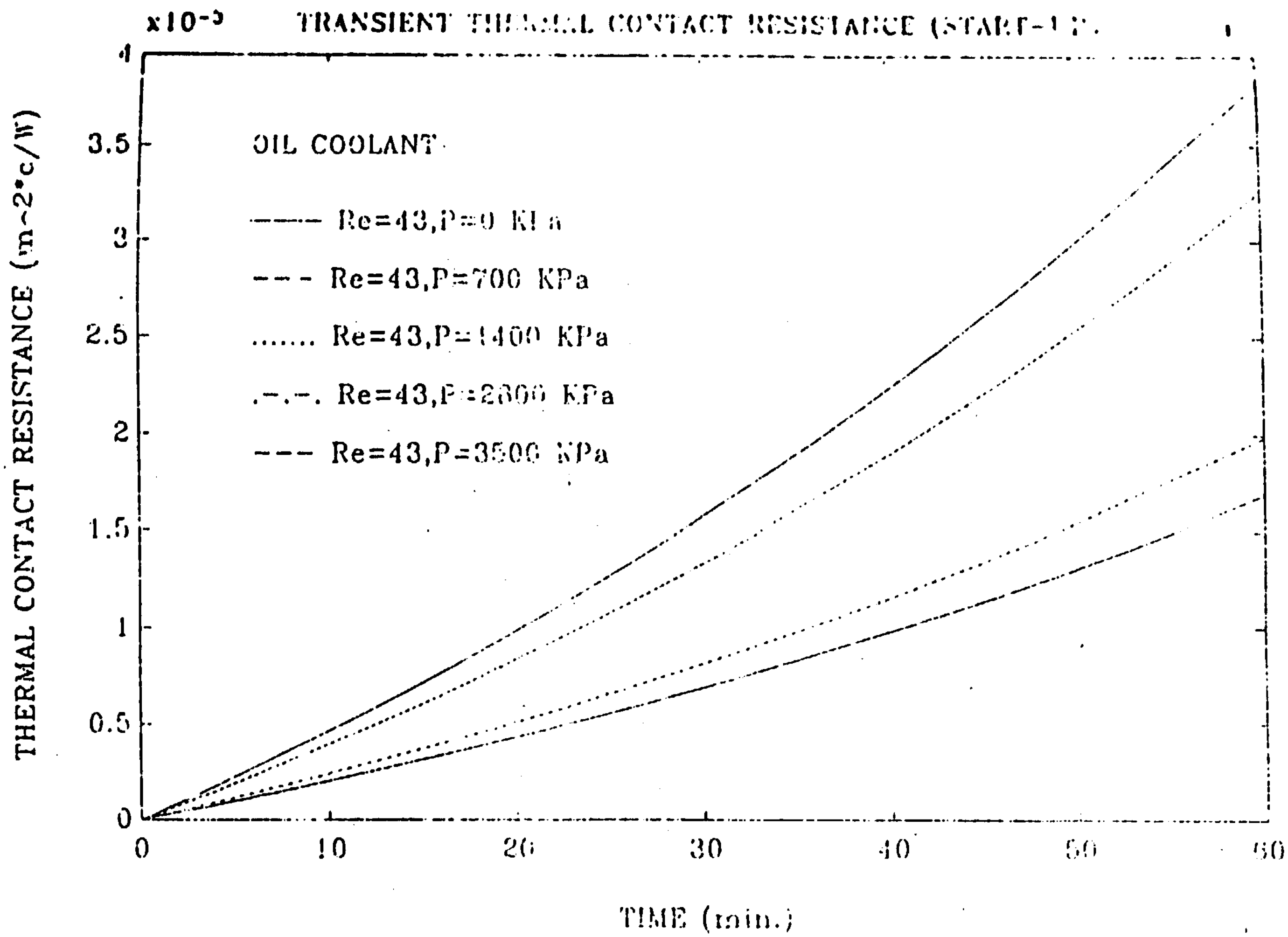


Figure 46. Analytical Transient Thermal Contact Resistance (Start-Up Condition with Oil Coolant, Re = 43).

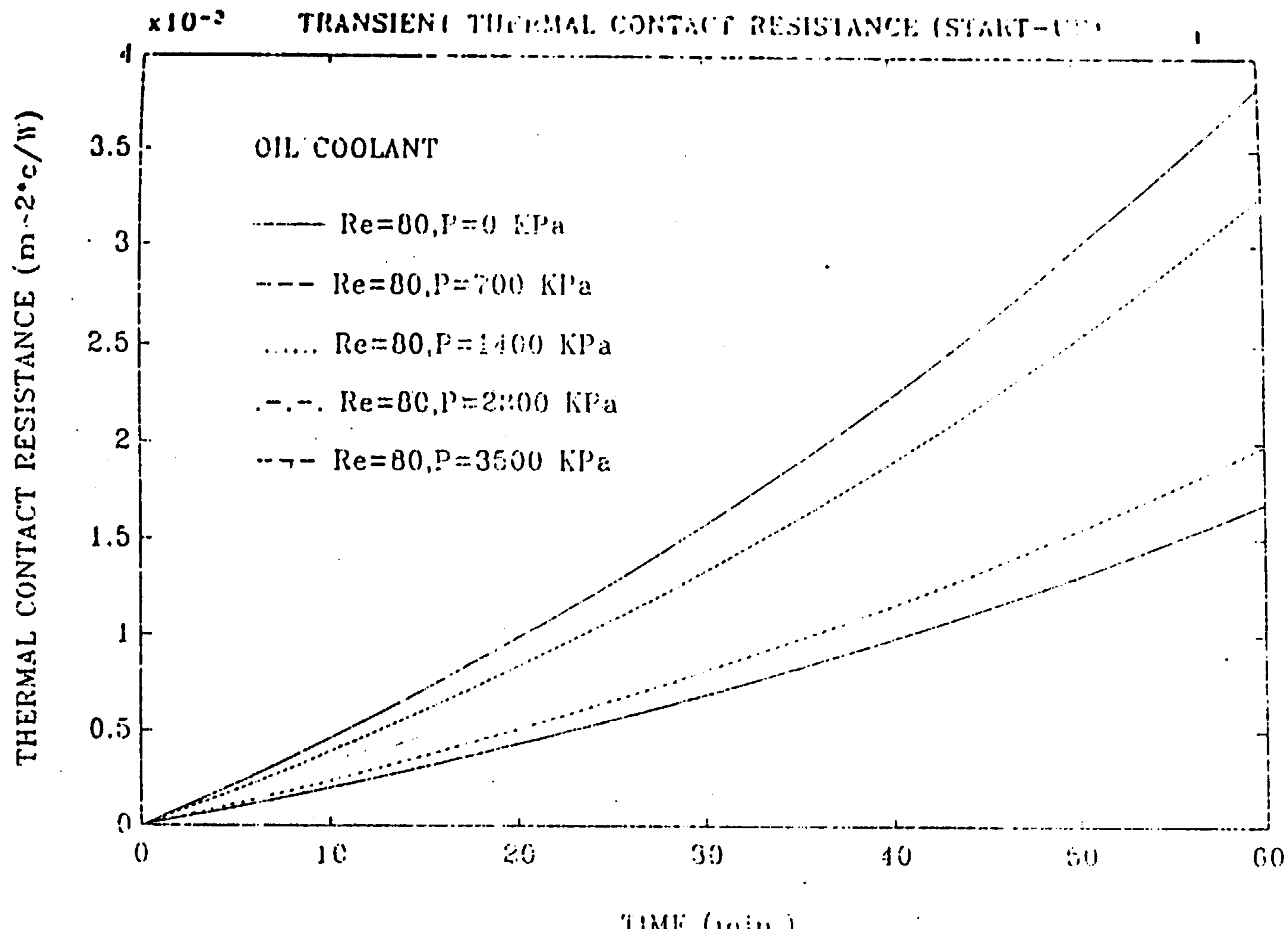


Figure 47. Analytical Transient Thermal Contact Resistance (Start-Up Condition with Oil Coolant, Re = 80).

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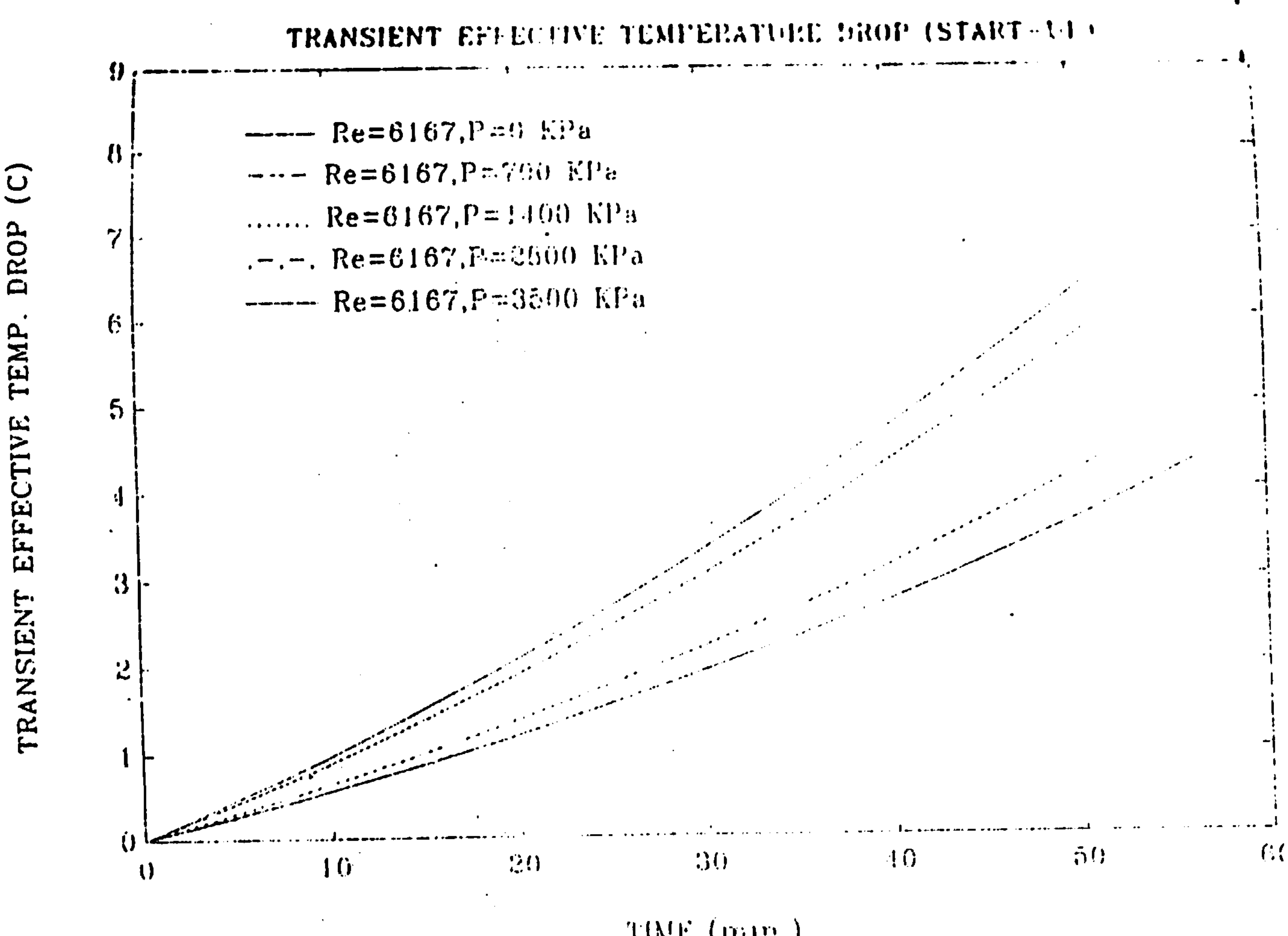


Figure 48. Effective Temperature Drop (Start-Up Condition with Water Coolant, Re = 1250).

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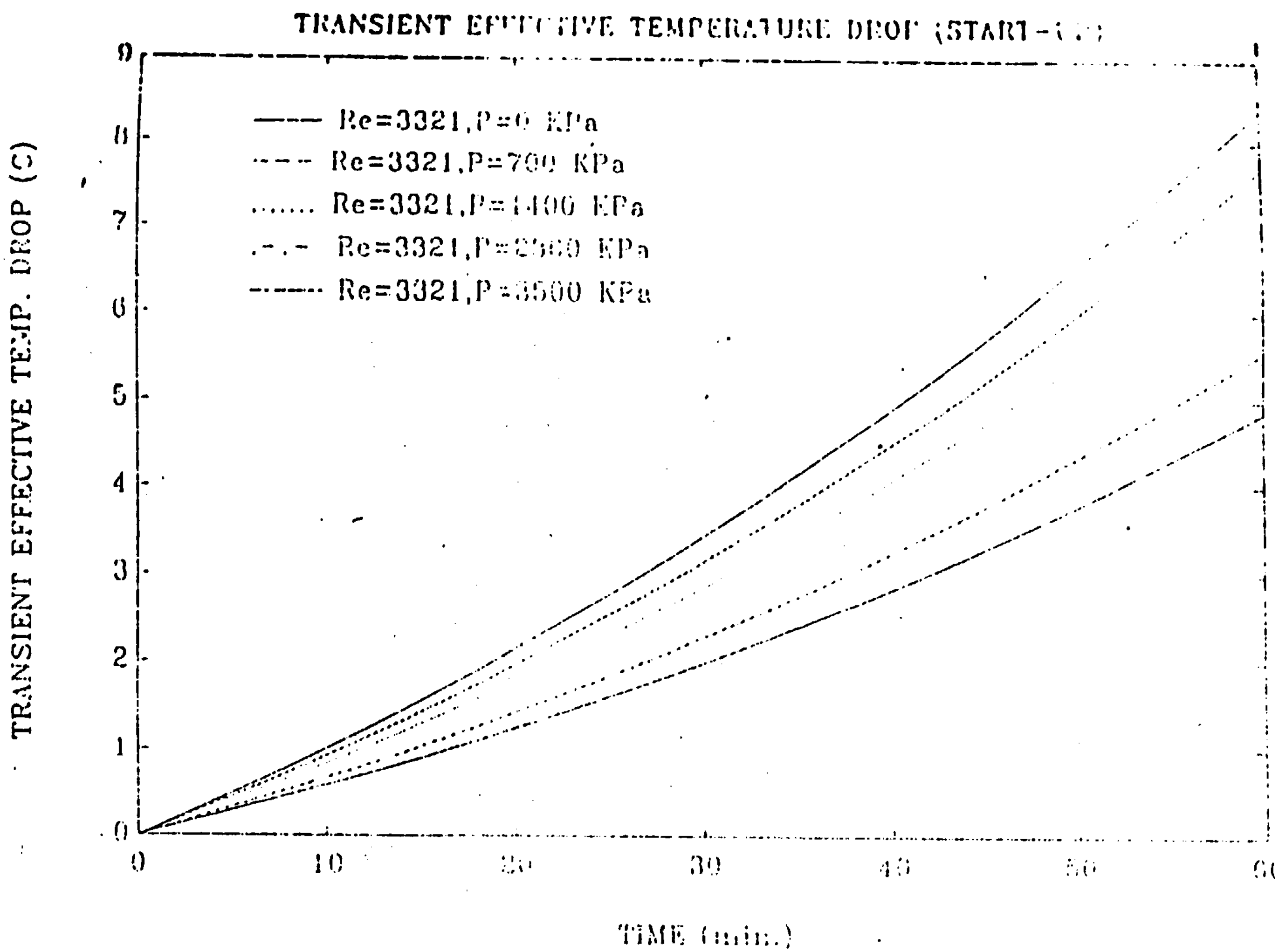


Figure 49. Effective Temperature Drop (Start-Up Condition with Water Coolant, Re = 3321).

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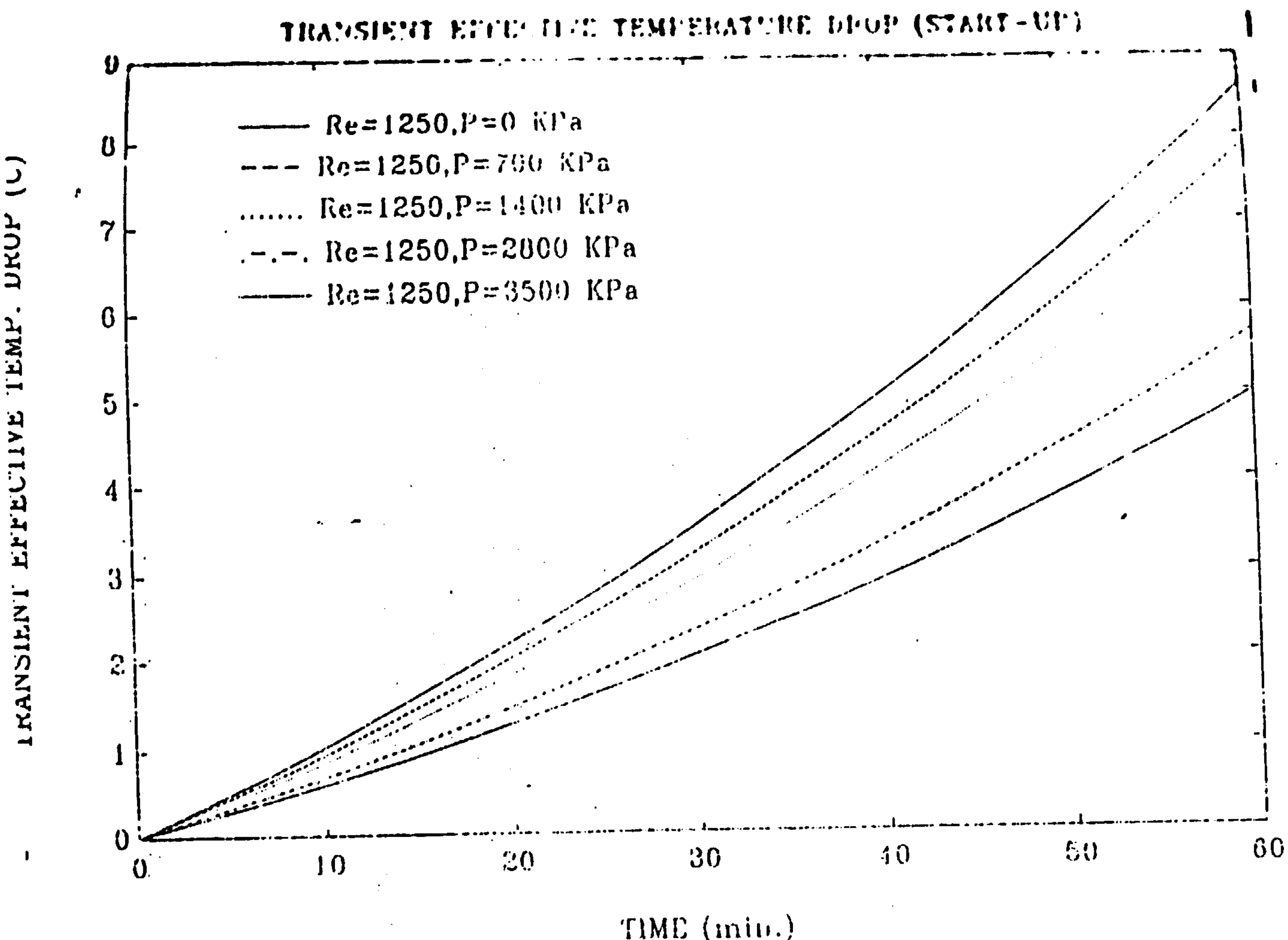


Figure 50. Effective Temperature Drop (Start-Up Condition with Water Coolant, Re = 6167).

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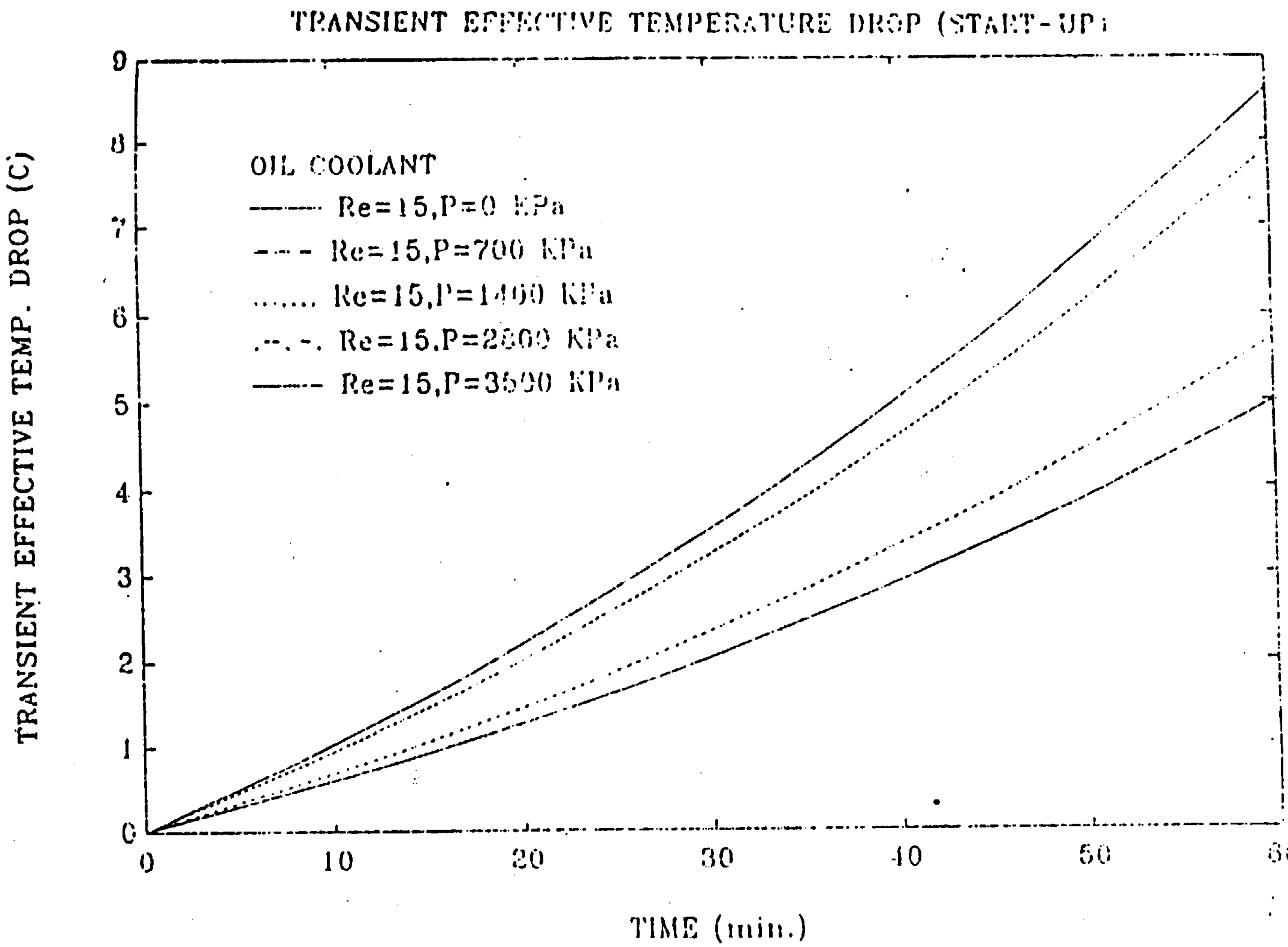


Figure 51. Effective Temperature Drop (Start-Up Condition with Oil Coolant, Re = 15)

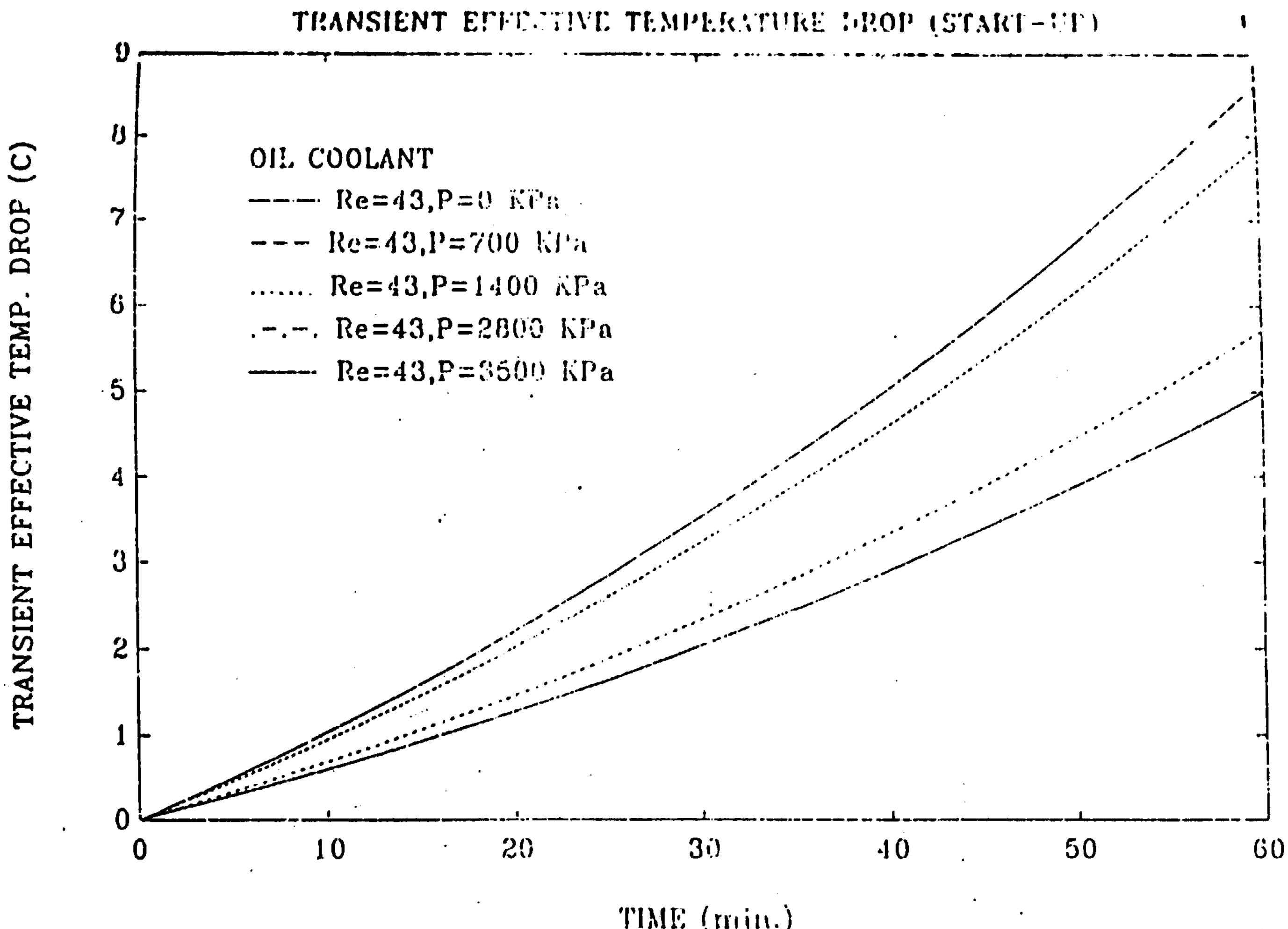

Figure 52. Effective Temperature Drop (Start-Up Condition with Oil Coolant, RE = 43).

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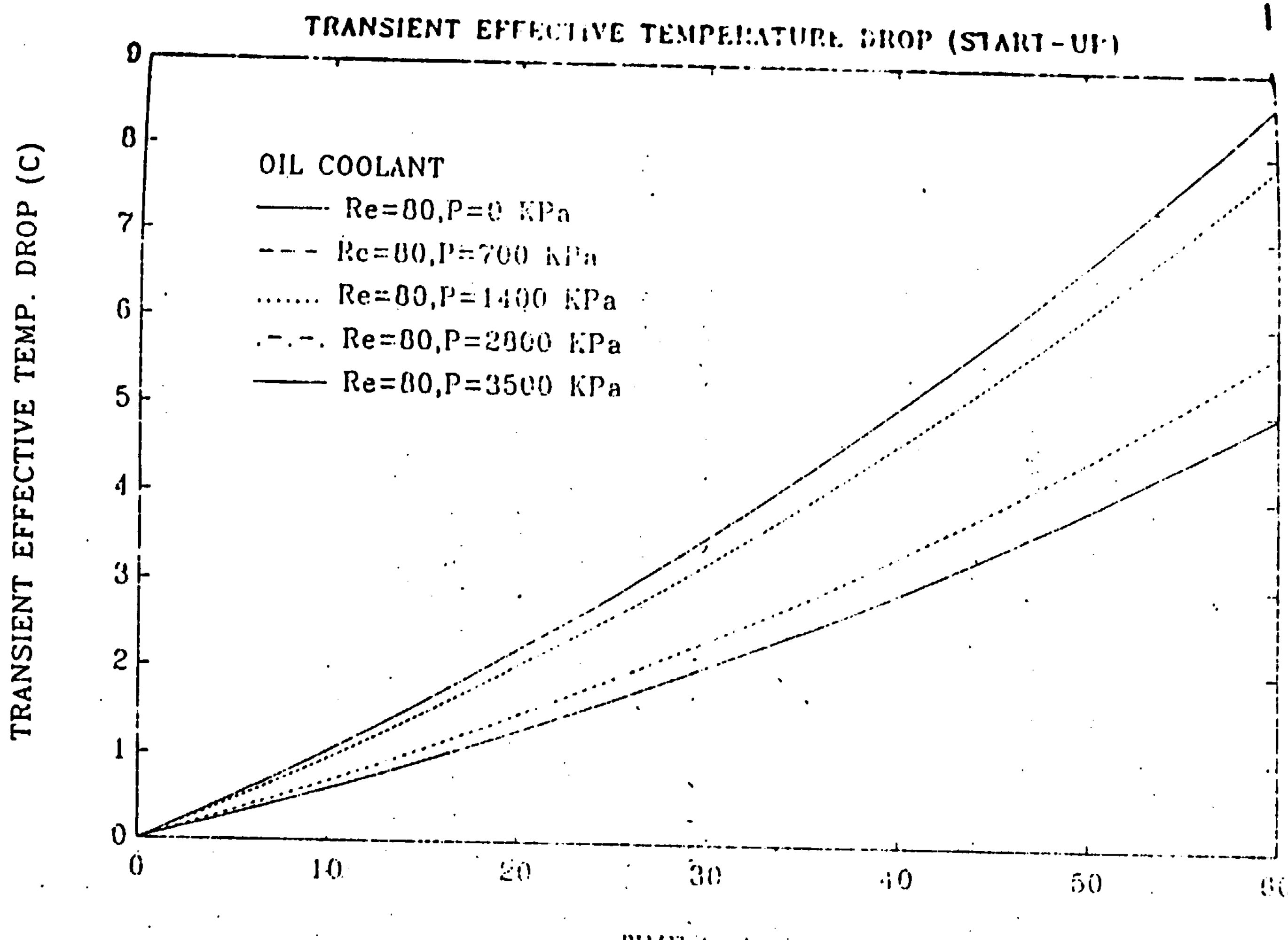


Figure 53. Effective Temperature Drop (Start-Up Condition with Oil Coolant, Re = 80).

#### 4.3.1.3 Calculated Transient Overall Heat Transfer Coefficient

It is important to calculate the transient overall heat transfer coefficient utilizing the correlation results of the transient convective heat transfer coefficient and the transient thermal contact resistance during a start-up process to determine the accuracy of the developed correlations to calculate the value of (U(t)). The following previously developed equation was utilized to calculate (U(t)):

$$U(t) = \frac{1}{\left[\frac{1}{h(t)} + \frac{\Delta x}{K_{total}} + r_c(t)\right]}$$

Results using the developed correlation were utilized to generate results for the two incompressible working fluids:

(a) <u>Water Coolant (Re = 1250 to Re = 6167)</u>

To summarize only the minimum average and maximum Re numbers were used here as exhibited by Figure 54 to Figure 56 in order to demonstrate the effect of the stack-pressure and the flow characteristics on the (U(t)) value.

(b) <u>Oil Coolant (Re=15 to Re=80</u>

Figure 57 to Figure 59 summarizes part of the calculated results for all applied stack pressure and for maximum average and minimum flow rate.

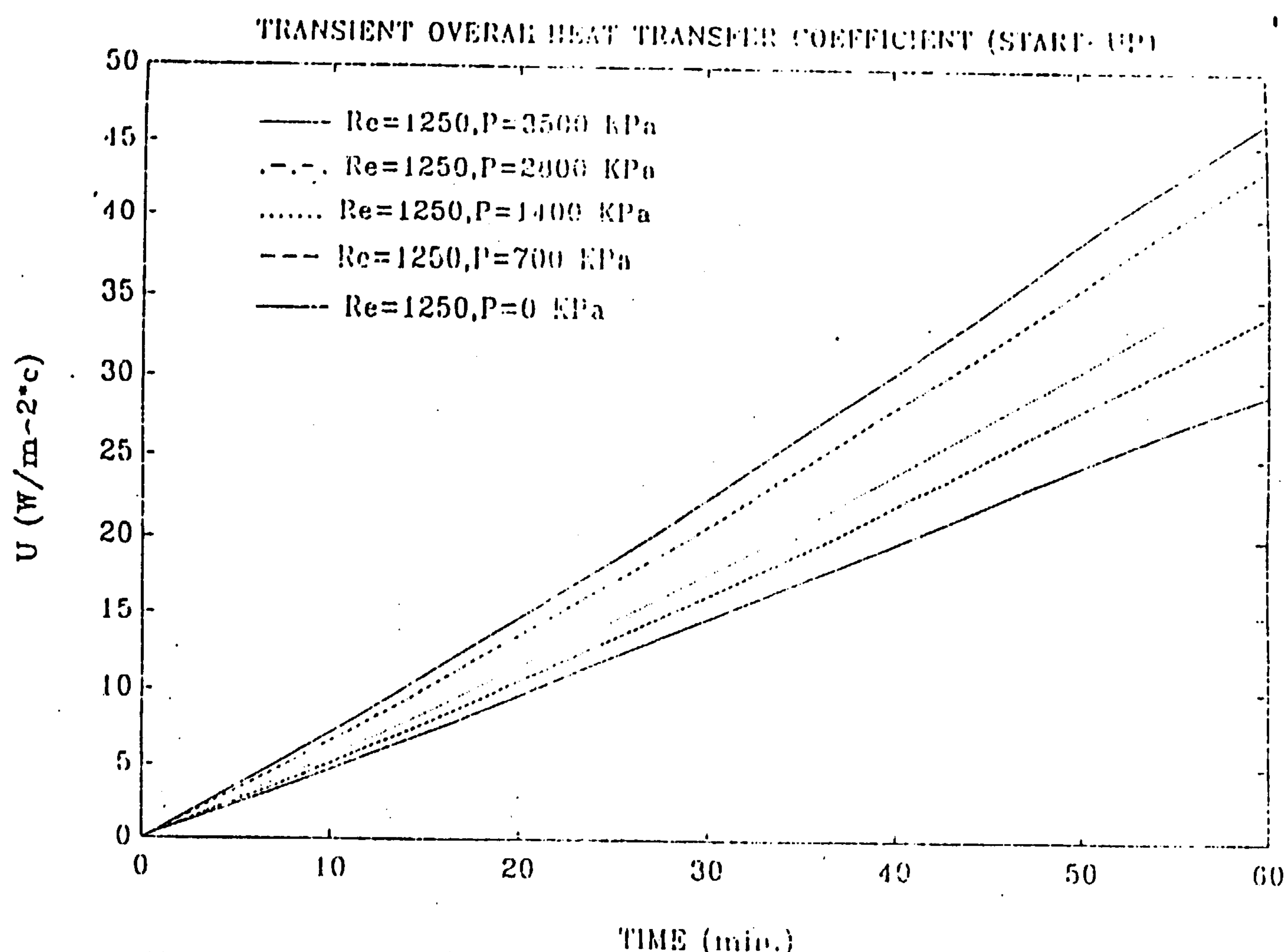


Figure 54. Analytical Transient Overall Heat Transfer Coefficients (Start-Up Condition with Water Coolant, Re = 1250).

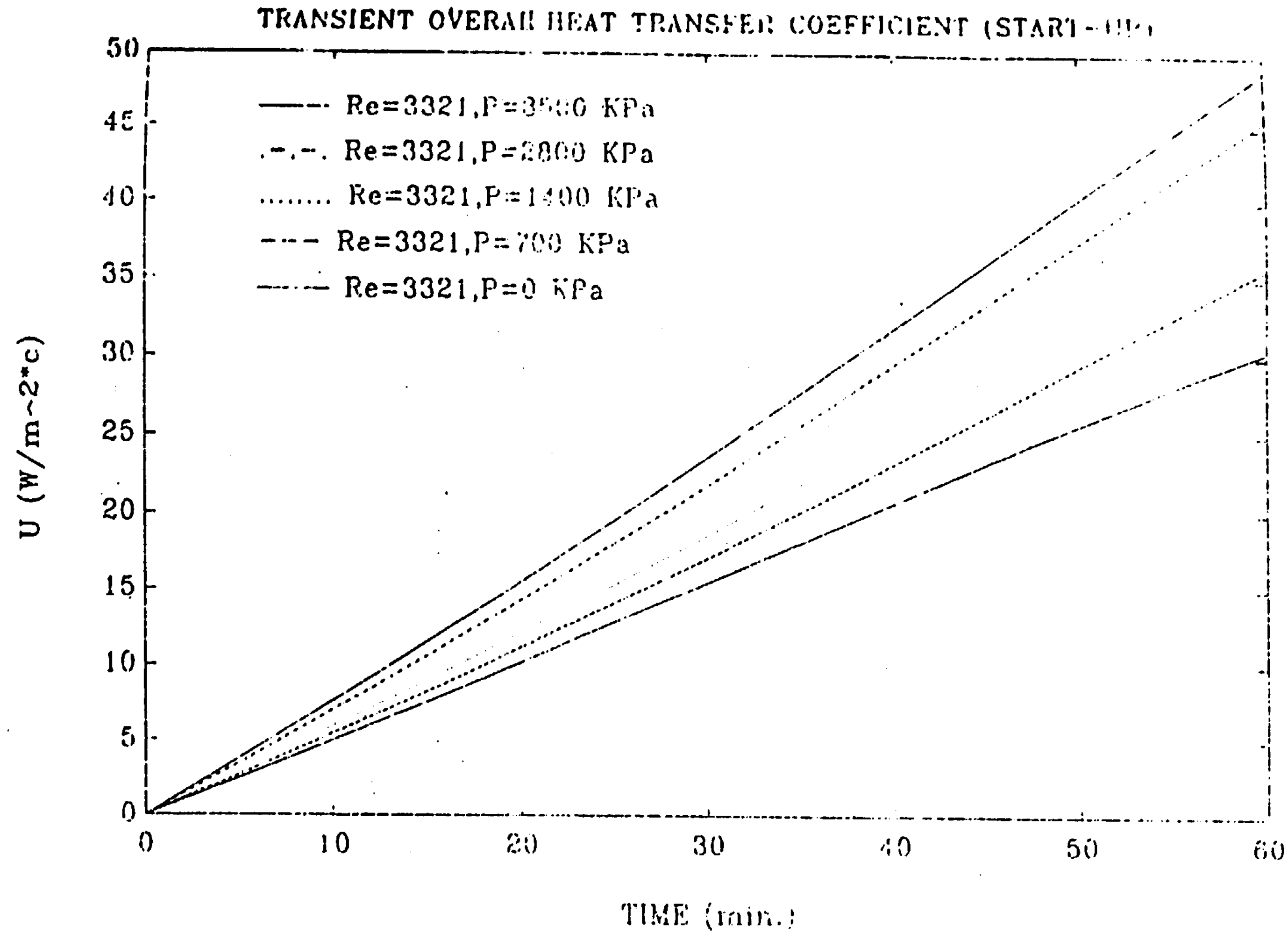

Figure 55. Analytical Transient Overall Heat Transfer Coefficients (Start-Up Condition with Water Coolant, Re = 3321)

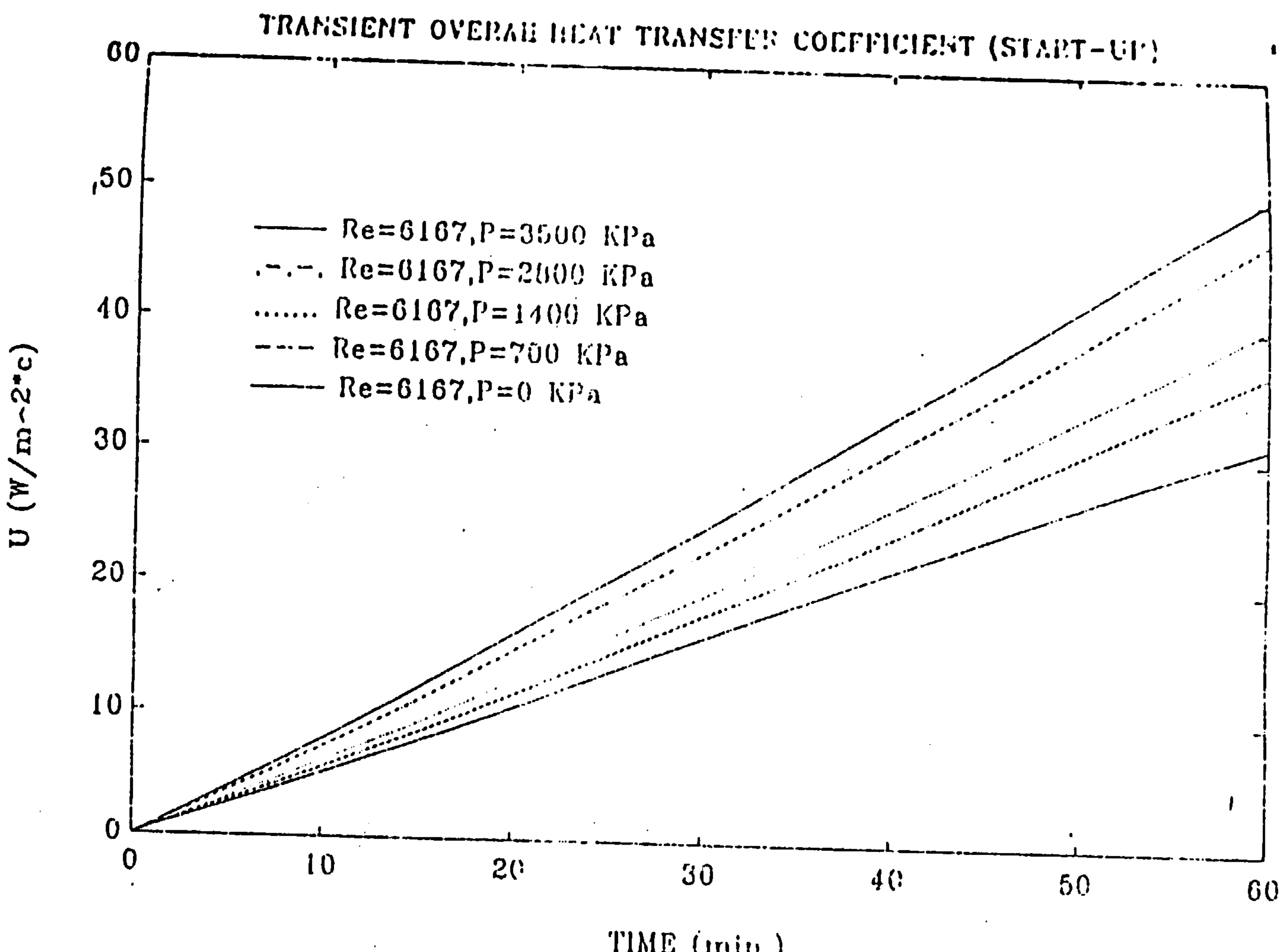


Figure 56. Analytical Transient Overall Heat Transfer Coefficients (Start-Up Condition with Water Coolant, Re = 6167).

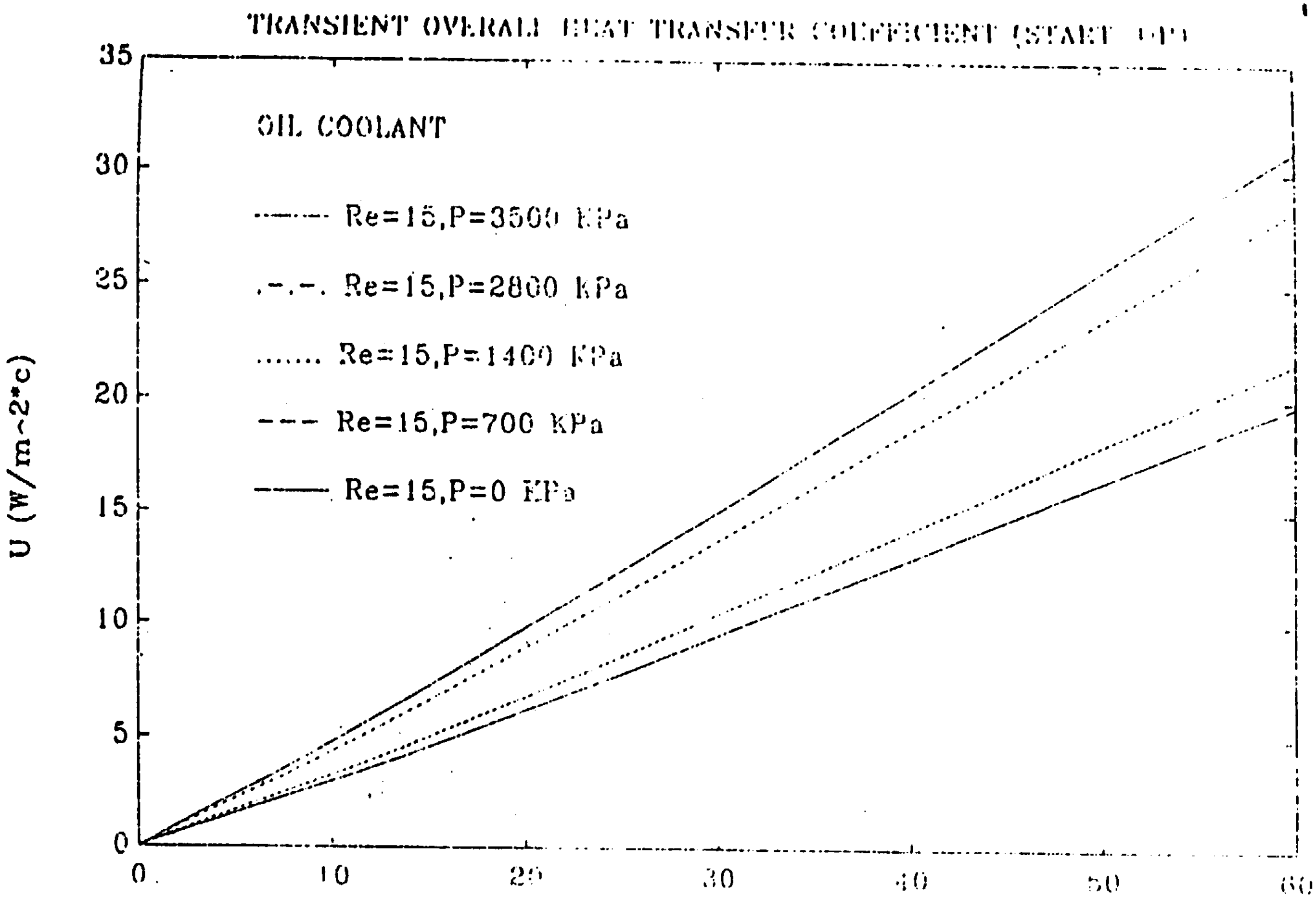


Figure 57. Analytical Transient Overall Heat Transfer Coefficients (Start-Up Condition with Oil Coolant, RE = 15).

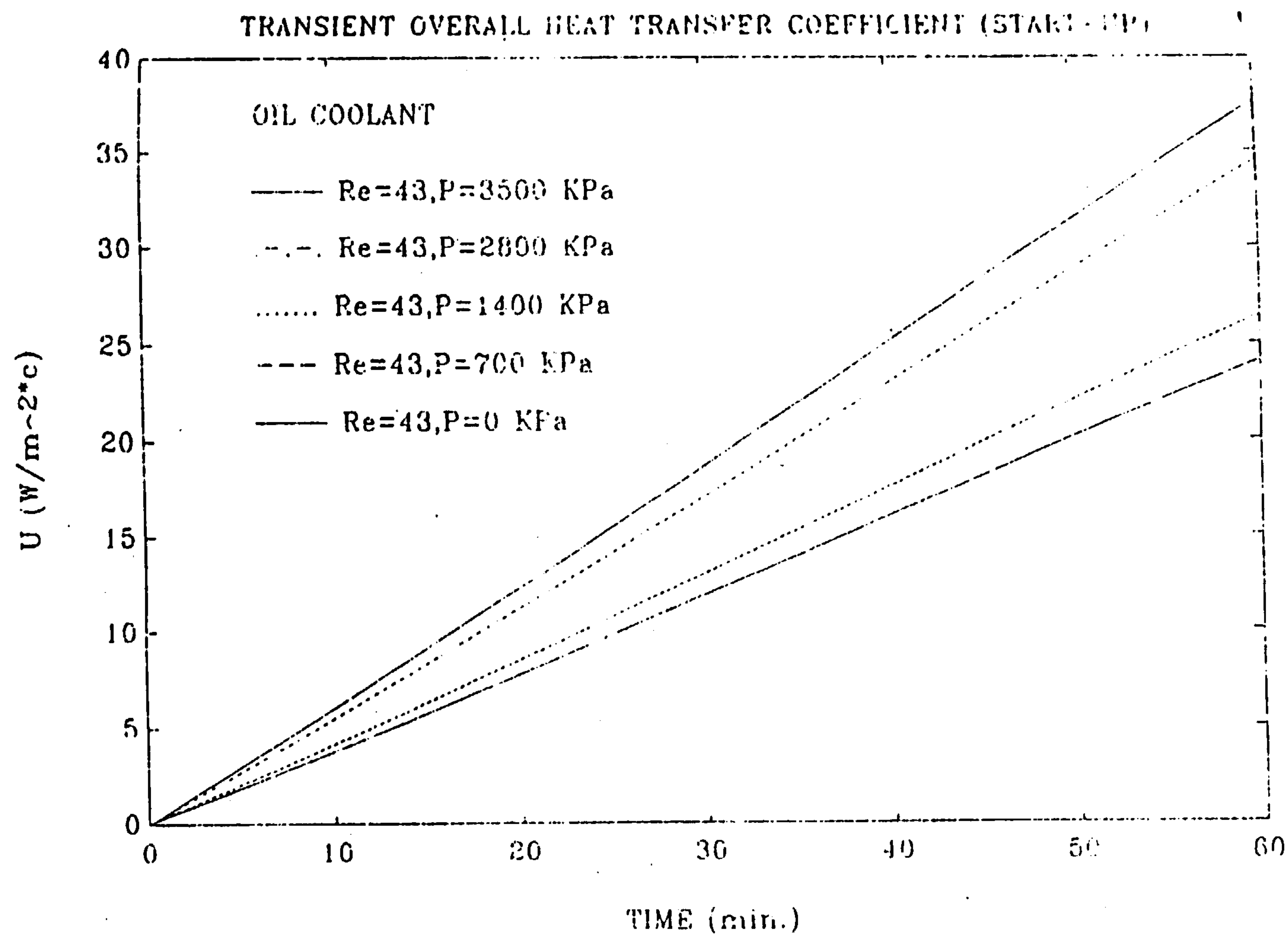


Figure 58. Analytical Transient Overall Heat Transfer Coefficients (Start-Up Condition with Oil Coolant, Re = 43).

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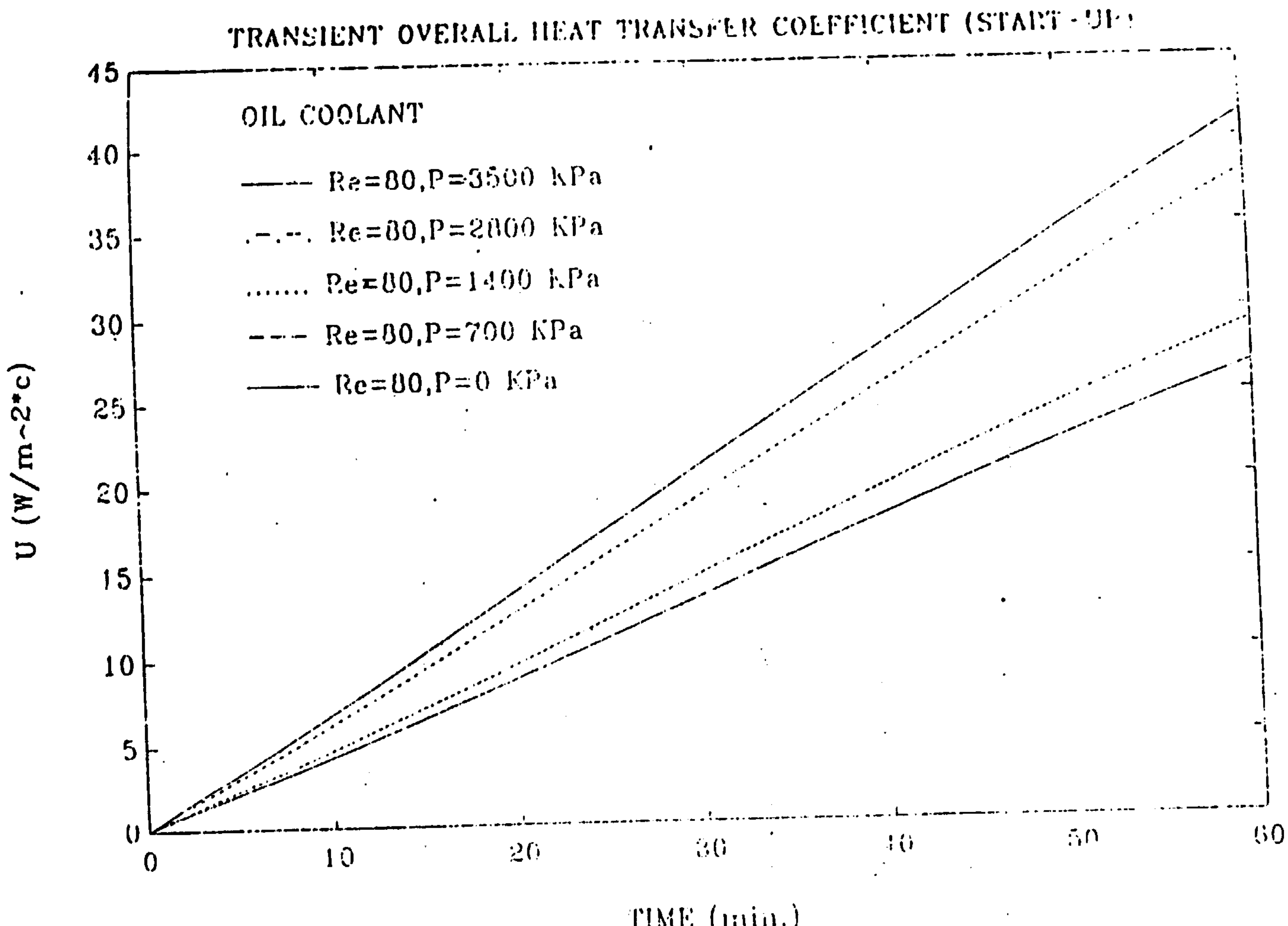


Figure 59. Analytical Transient Overall Heat Transfer Coefficients (Start-Up Condition with Oil Coolant, Re = 80).

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### 4.3.2 Shut-Down Process

In this section the shut-down mathematical correlation will be developed to demonstrate the variation of heat transfer characteristics of the fuel cell modules for the different considered operation conditions.

#### 4.3.2.1 Transient Convection Heat Transfer Coefficient and the Transient Nusselt Number

The following general correlation can be formulated for the shut-down process:

$$h_s(t) = A_{s1} * H_1(Re,Pr) * [\exp\ ( {}_{s1}t + \alpha_{s1}o)] \tag{25}$$

and

$$Nu_s(t) = A_{s1} * H_2(Re,Pr) * [\exp( {}_{s2}t + \alpha_{s2}o)] \tag{26}$$

where

$A_{s1}$, $A_{s2}$ = shut-down initial condition constants.

$H_1(Re,Pr)$, $H_2(Re,Pr)$ = function of the flow rate and the fluid properties.

$\lambda_{s1}$, $\lambda_{s2}$ = shut-down time constants.

$\alpha_{s1}$, $\alpha_{s2}$ = operation condition constants.

The developed mathematical correlation utilizing the generated experimental results can be written for both working fluids as follows:

(a) <u>Water Coolant (Re=1250 to Re = 6167</u>

$$h_s(t) = 70.088*(Re^{0.05779})*(Pr^{0.01433})* [\exp\ (-0.00891t + 0.000123\ o) \tag{27}$$

$$Nu_s(t) = 0.769*(Re^{0.05632})*(Pr^{0.0385})* [\exp(-0.01083t + 0.000124\ o)] \tag{28}$$

Figure 60 demonstrates calculated Nusselt number results when water was used as a coolant.

(b) <u>Oil Coolant (Re=15 to Re=80)</u>

$$h_s(t) = 35.044*(Re^{0.21506})*(Pr^{7.614*10-3})$$

$$[\exp(-0.00901t + 1.356*10^{-4}\ o) \qquad (29)$$

$$Nu_s(t) = 0.771*(Re^{0.2105})*(Pr^{3.86*10-3})*$$

$$[\exp(-0.01082t + 1.356*10^{-4}\ o)] \qquad (30)$$

The calculated values for the Nu number is stated as a function of time for the Re number during a shut-down process when oil is used as a coolant. Refer to Figure 61.

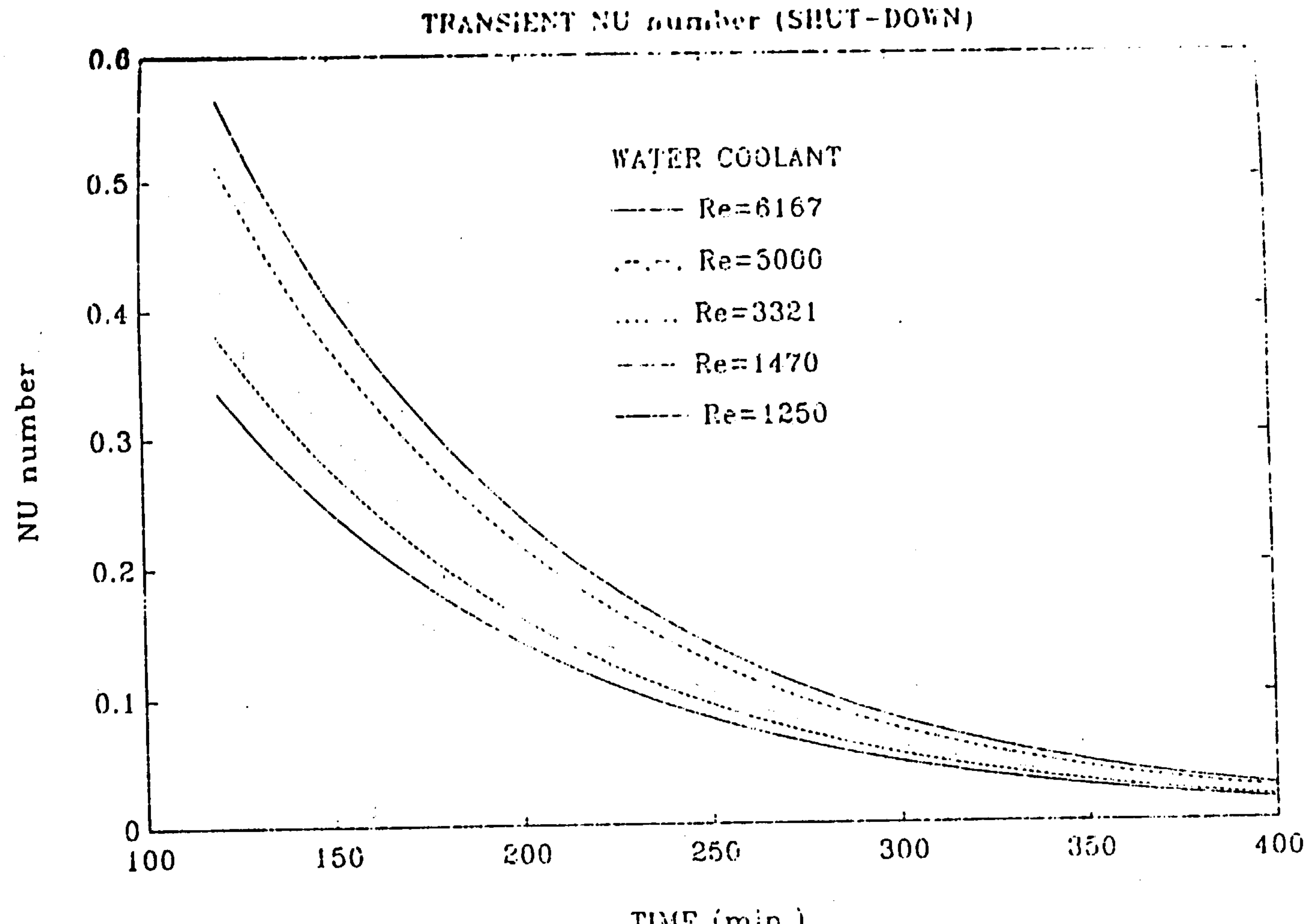


Figure 60. Analytical Transient Nusselt Number (Shut-Down Condition with Water Coolant).

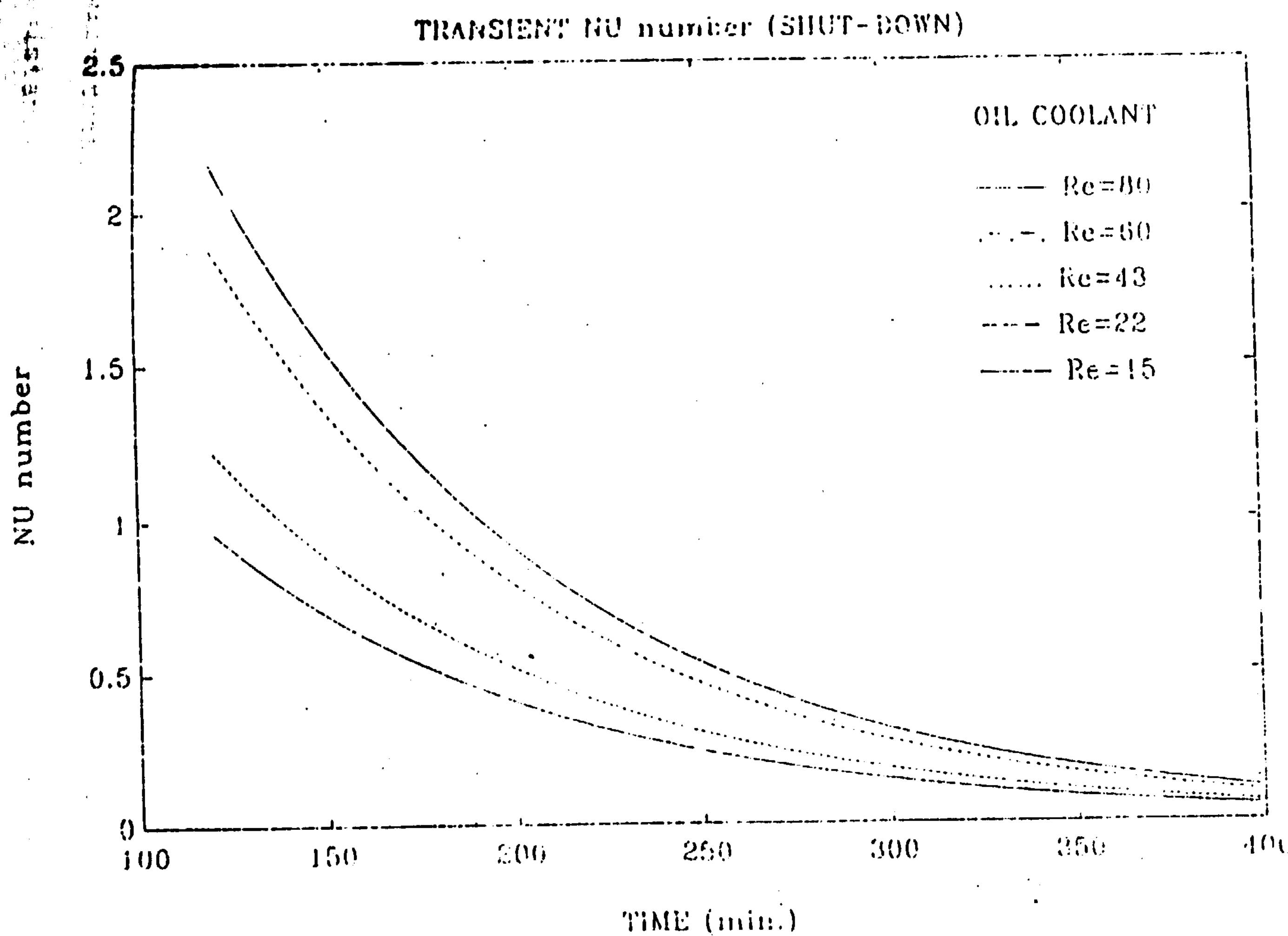


Figure 61. Analytical Transient Nusselt Number (Shut-Down Condition with Water Coolant Re = 1250).

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### 4.3.2.2 Contact Resistance and the Effective Temperature Drop

During a shut-down process the mathematical correlations that simulate the change of contact resistance and the variation of transient thermal contact resistance can be expressed as follows:

$$r_{cs}(t) = A_{s3}W_{s1}(P)*[\exp(\lambda_{s3}t + \gamma_{s1}o)] + A_{s4}*W_{s2}(P) \qquad (29)$$

$$\Delta T_s(t) = [A_{s5} - W_{s3}(P)][\exp(\lambda_{s4}t + \gamma_{s2}o)] + [A_{s6} - W_{s4}(P)] \qquad (30)$$

where

$A_{s3}$, $A_{s4}$, $A_{s5}$ and $A_{s6}$ = constants.

$W_{s1}(P)$ = function of stack pressure.

$\lambda_{s3}$, $\lambda_{s4}$ = shut-down time constant.

o = operation condition parameter.

$\gamma_{s1}$, $\gamma_{s2}$ = operation condition constants.

(a) Water Coolant (Re = 1250 to Re = 6167):

$$r_{cs}(t) = 0.00575*(e^{-0.000236p})*[\exp(-0.00391t - 0.179*10^{-3}\ o)] + 1.802*10^{-3} * (e^{0.000236p}) \qquad (31)$$

$$\Delta T_s(t) = [14.986-(0.9597*10^{-2})P][\exp(-0.0046t-0.101*10^{-4}\ o)] + [6.129 - (0.7365*10^{-2})P] \qquad (32)$$

Figure 62 to Figure 64 and Figure 68 to Figure 70 demonstrates the variation of the transient thermal contact resistance and the effective temperature drop respectively with different applied stack pressure and Reynolds number

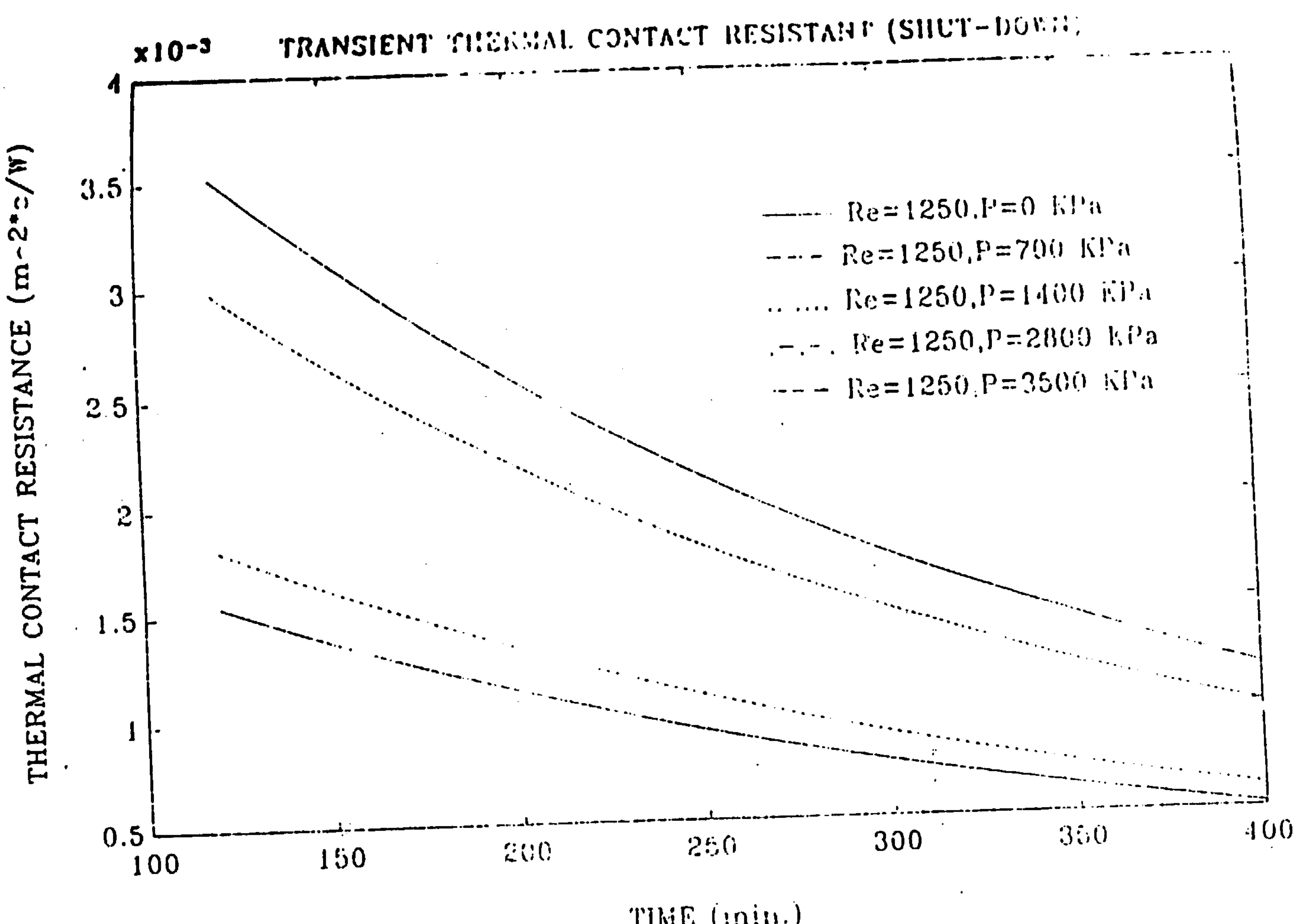


Figure 62. Analytical Transient Thermal Contact Resistance (Shut-Down Condition with Water Coolant Re = 1250).

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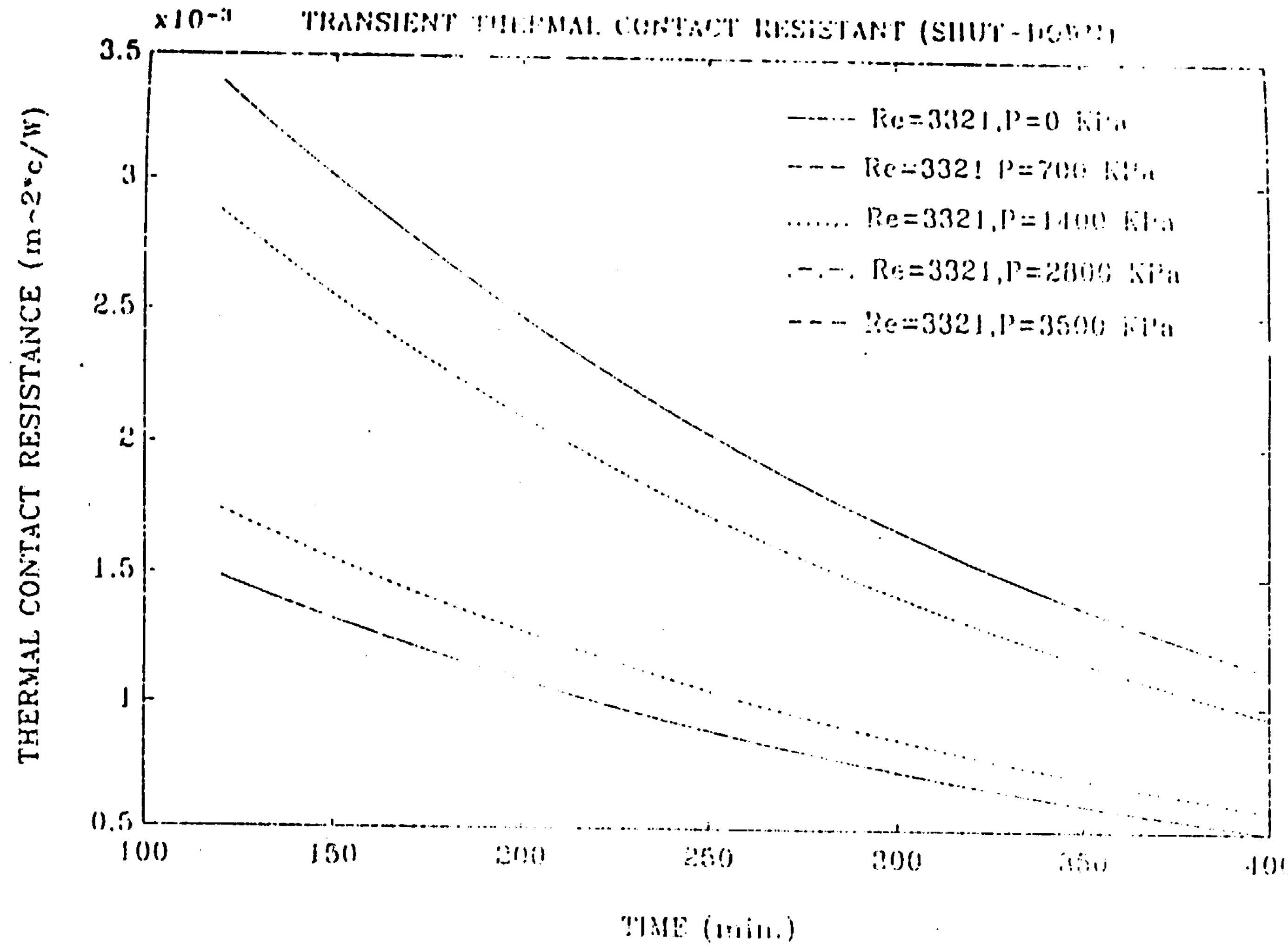


Figure 63. Analytical Transient Thermal Contact Resistance (Shut-Down Condition with Water Coolant, Re = 3321).

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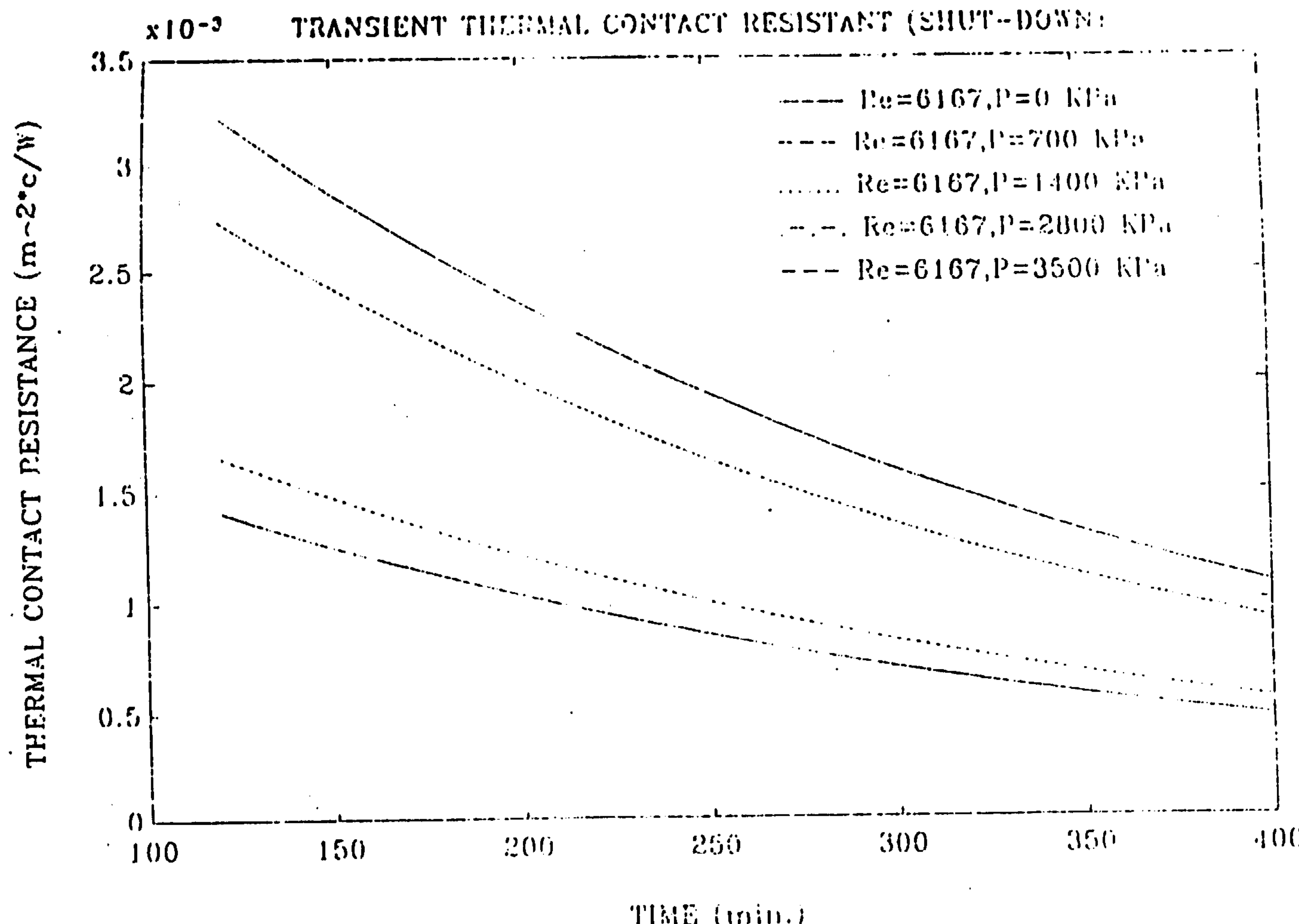


Figure 64. Analytical Transient Thermal Contact Resistance (Shut-Down Condition with Water Coolant, Re = 6167).

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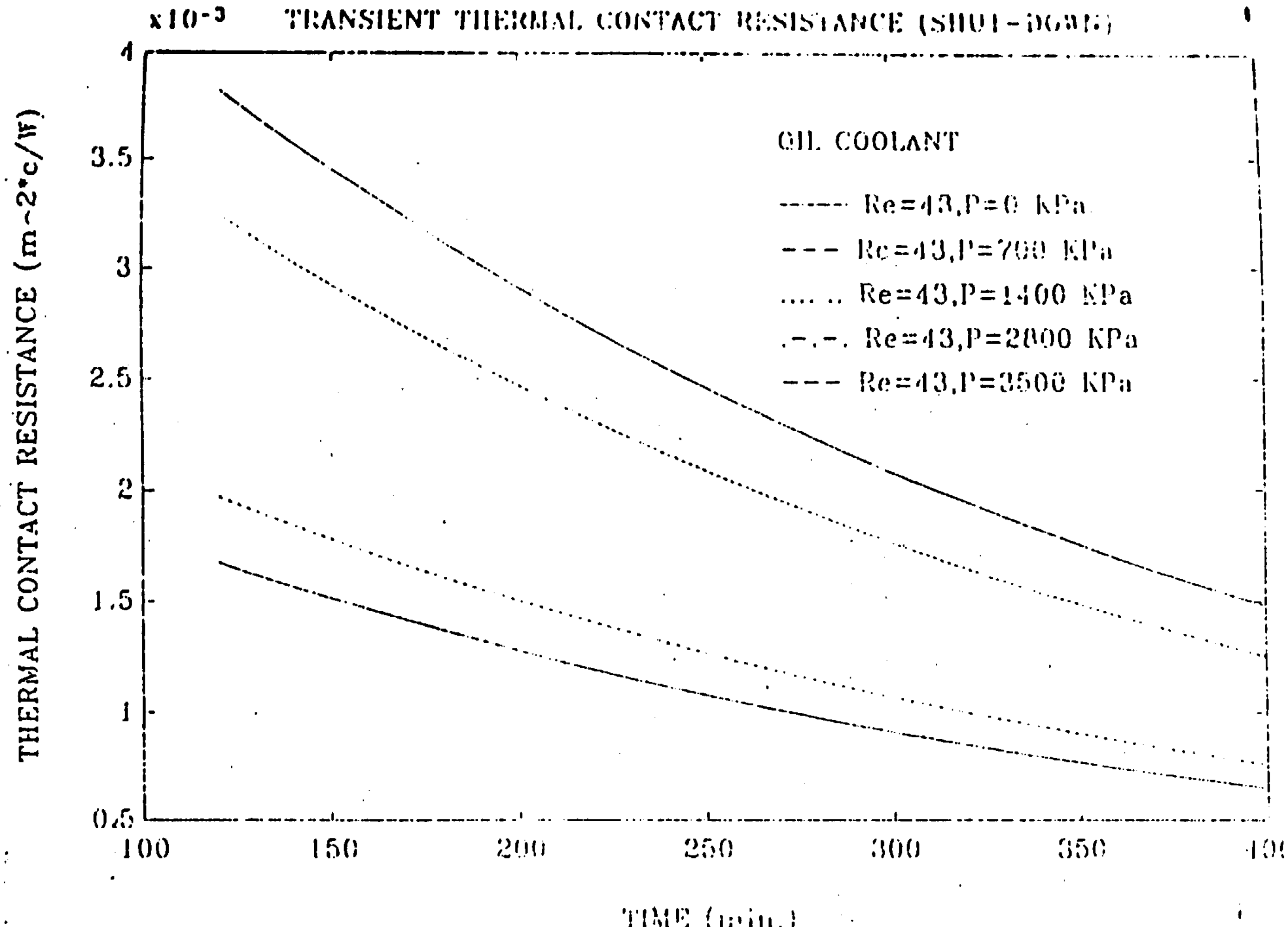


Figure 66. Analytical Transient Thermal Contact Resistance (Shut-Down Condition with Oil Coolant, Re = 43).

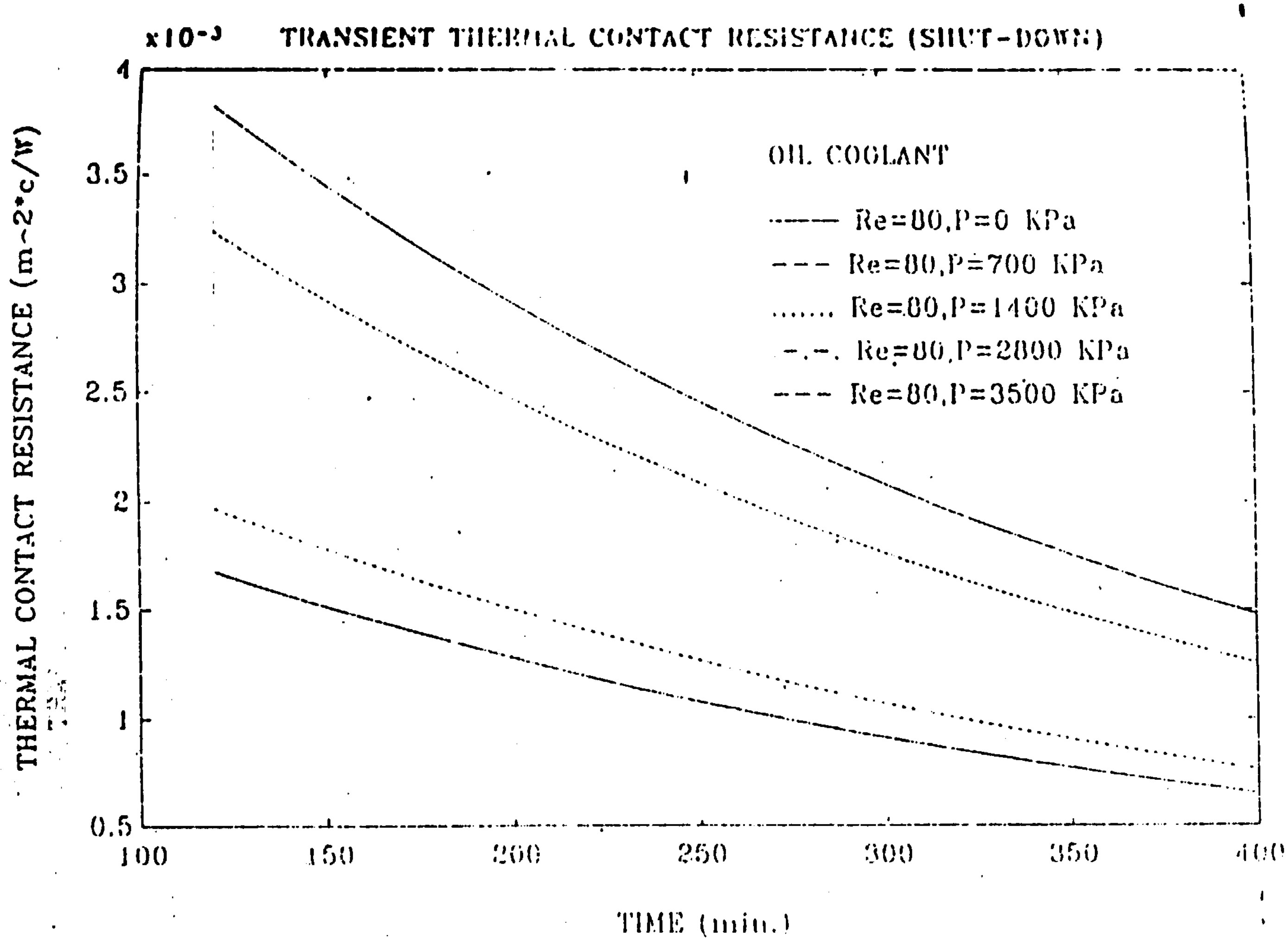


Figure 67. Analytical Transient Thermal Contact Resistance (Shut-Down Condition with Oil Coolant, Re = 80).

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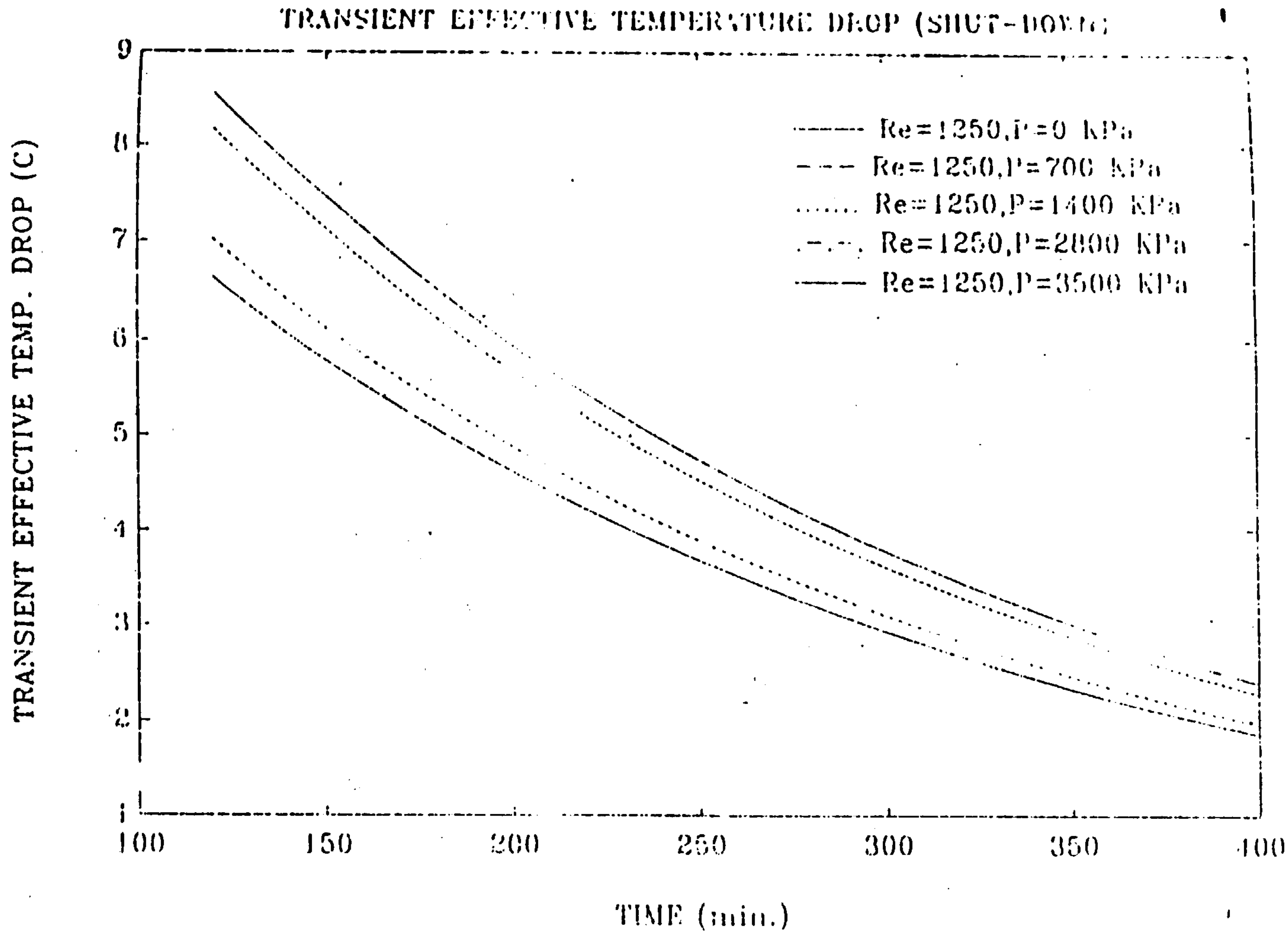


Figure 68. Effective Temperature Drop (Shut-Down Condition with Water Coolant, Re = 1250).

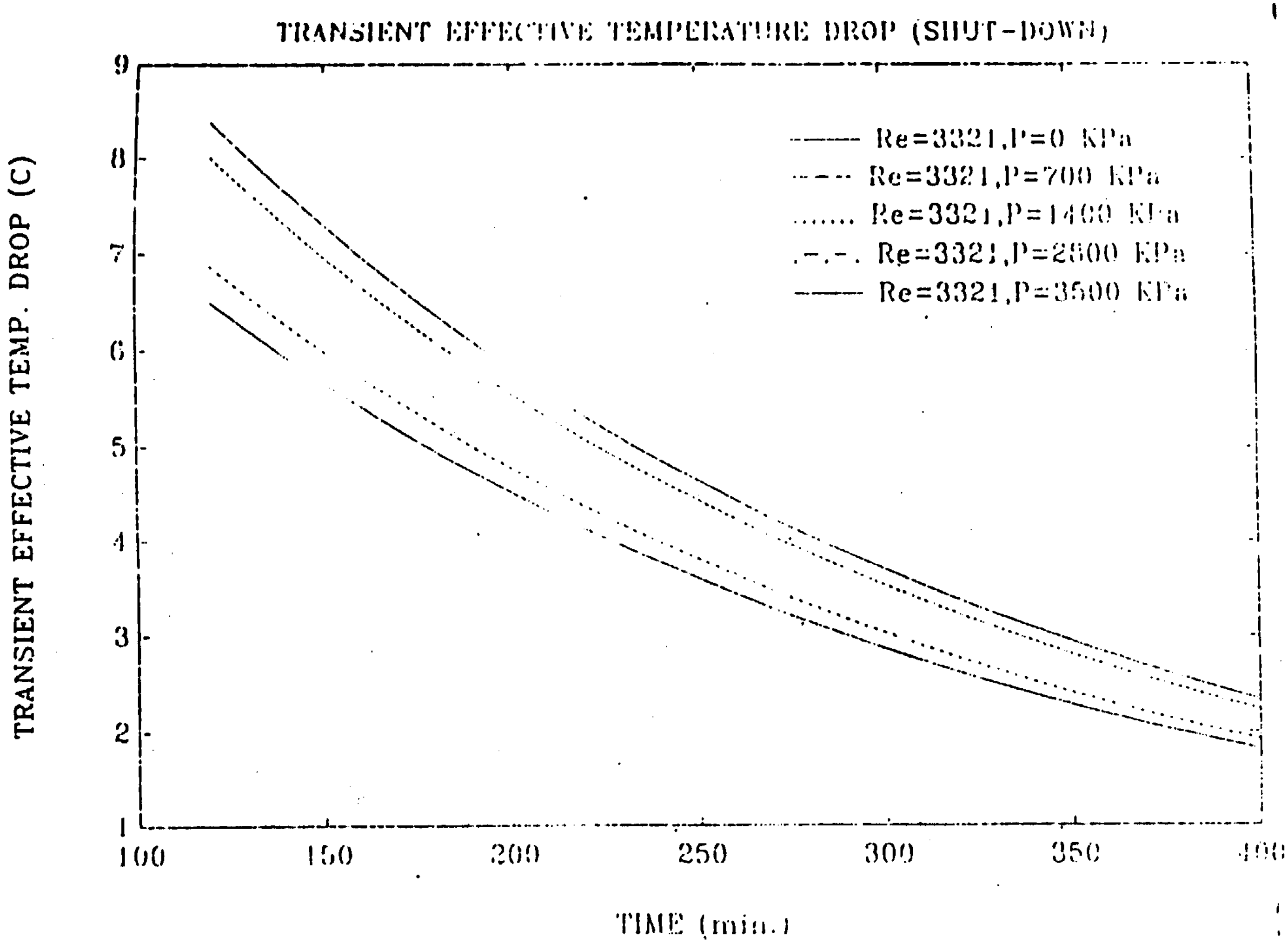


Figure 69. Effective Temperature Drop (Shut-Down Condition with Water Coolant, Re = 3321).

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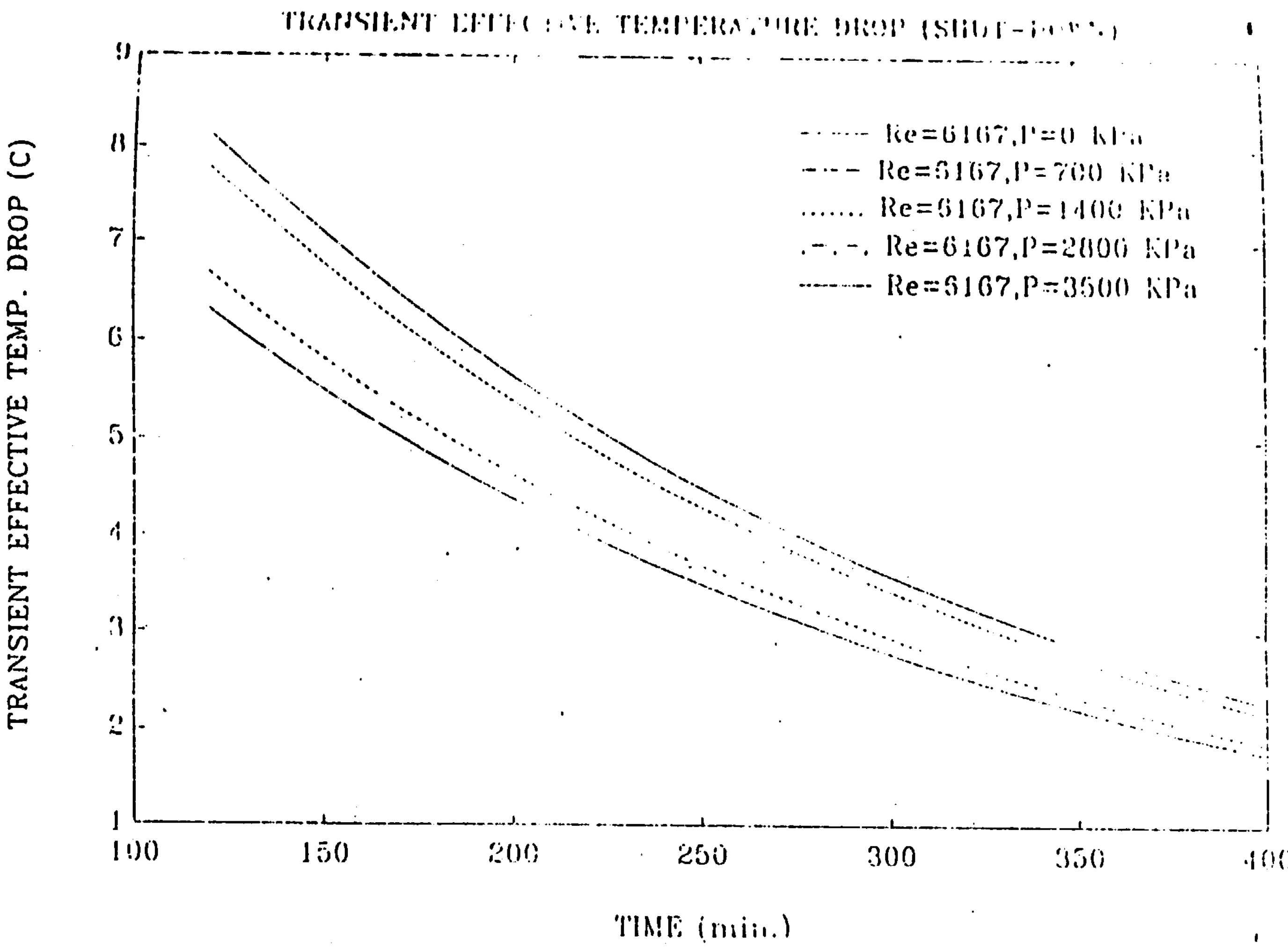


Figure 70. Effective Temperature Drop (Shut-Down Condition with Water Coolant, Re = 6167).

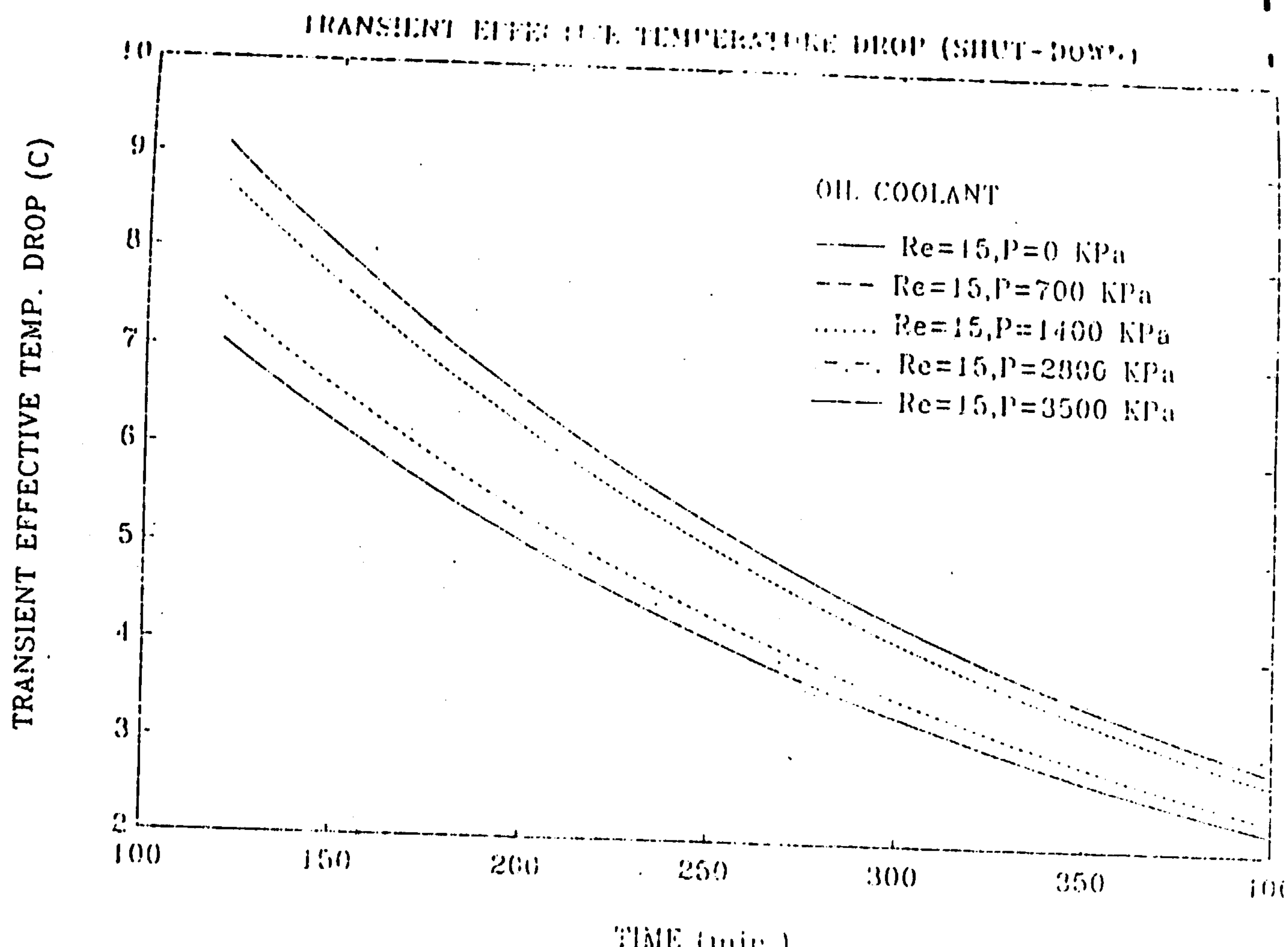


Figure 71. Effective Temperature Drop (Shut-Down Condition with Oil Coolant, Re = 15).

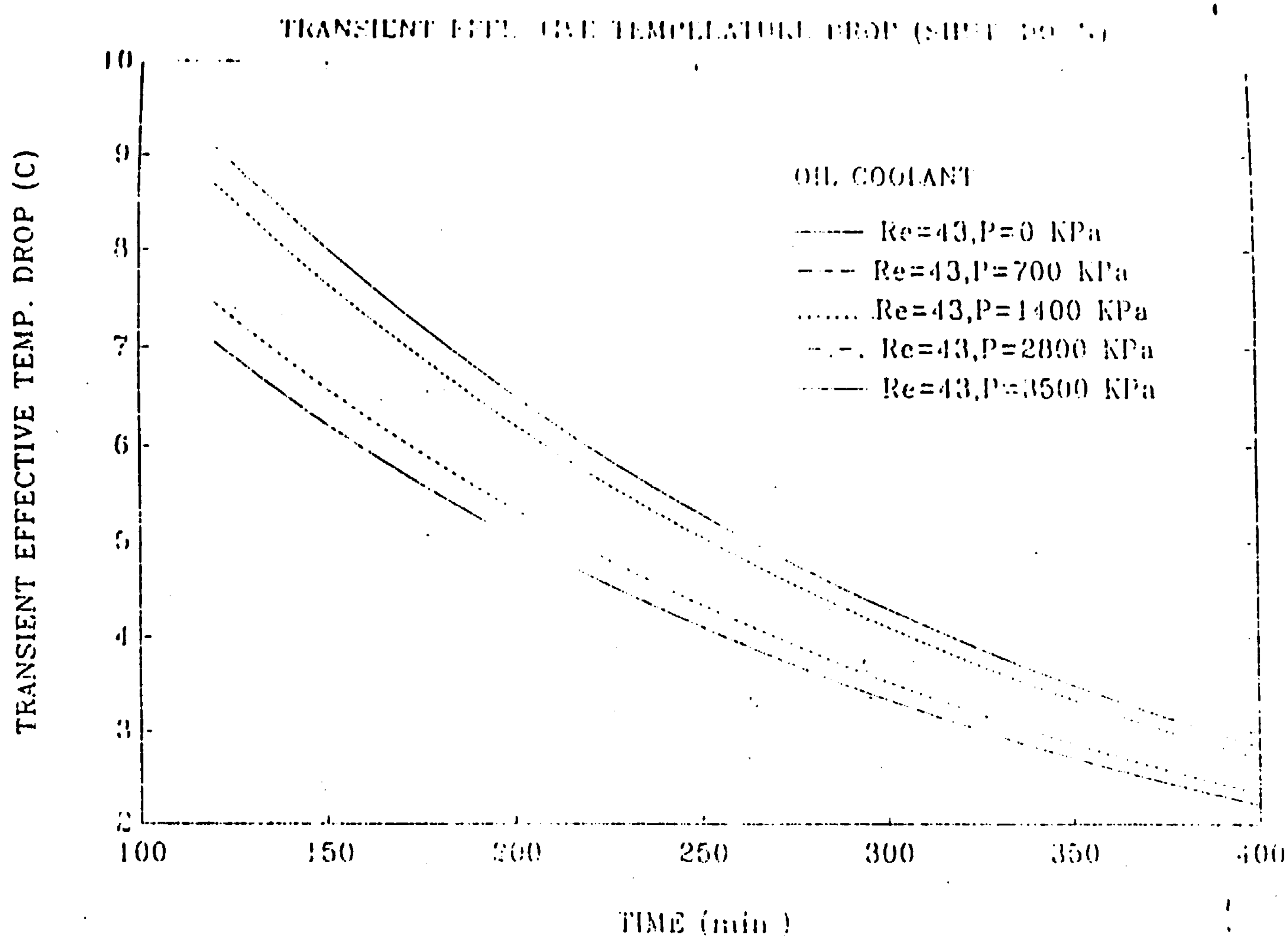


Figure 72. Effective Temperature Drop (Shut-Down Condition with Water Coolant, Re = 43).

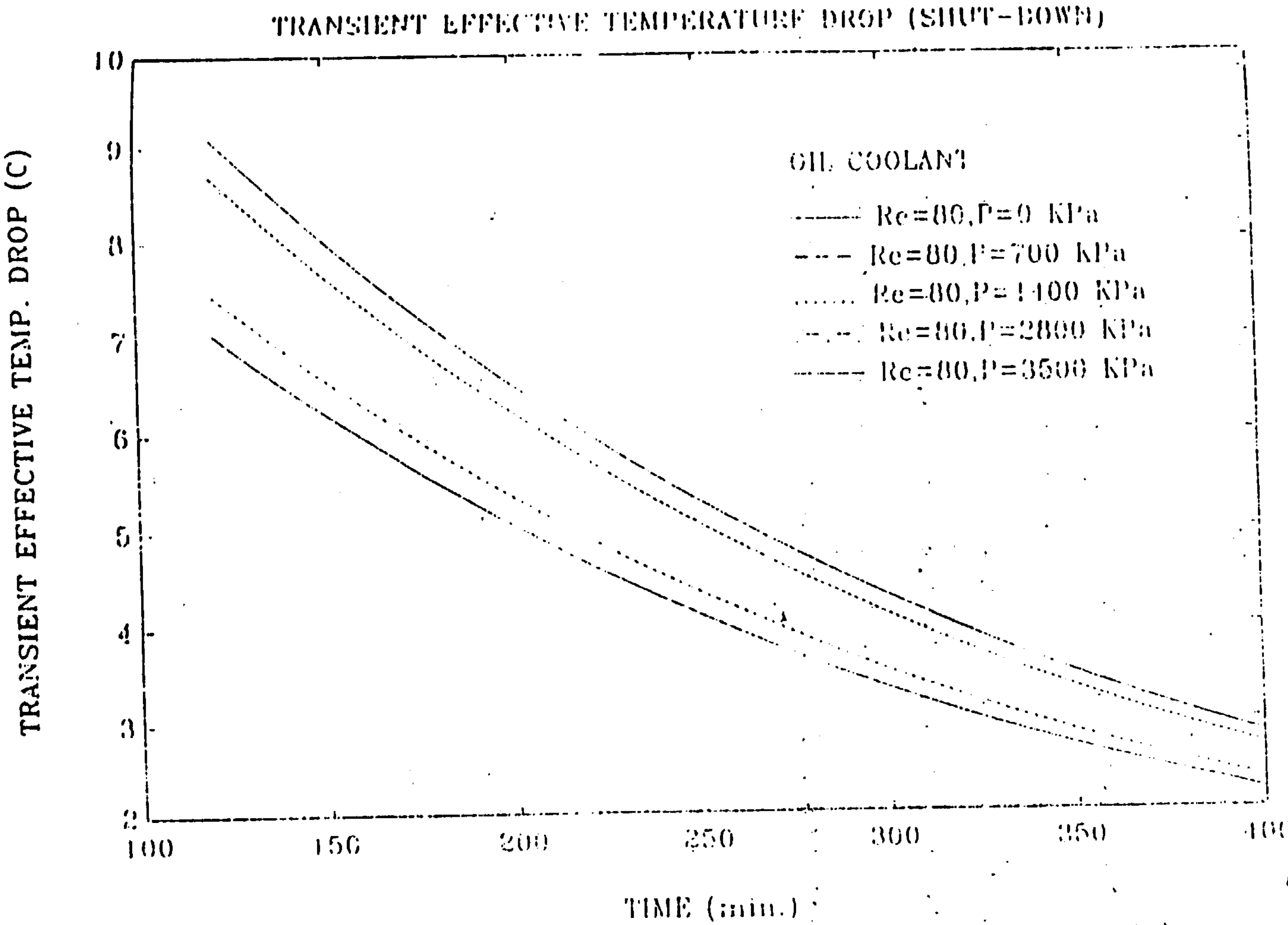


Figure 73. Effective Temperature Drop (Shut-Down Condition with Water Coolant, Re = 80).

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using water as a coolant.

(b) <u>Oil Coolant (Re=15 to Re=80):</u>

$$r_{rs}(t) = 0.00575*(e^{-2.36*10^{-4}p})*[\exp(-0.00339t - 1.79*10^{-5}\ o)] + 1.801*10^{-3} * (e^{-2.36*10^{-4}p}) \quad (33)$$

$$\overline{\Delta T_s}(t) = [14.986-(9.597*10^{-4})P][\exp(-4.155*10^{-3}t - 1.012*10^{-5}\ o)] + [6.129 - (7.366*10^{-4})P] \quad (34)$$

Figure 65 to Figure 67 and Figures 71 to 73 represents the generated results for equations [33] and [34] respectively, the maximum, average and the minimum coolant flow rates and the specified stack pressure during a shut-down process.

<u>Note</u>: The difference between the two above correlations set was just the exponential variable factor which will affect the rate slightly.

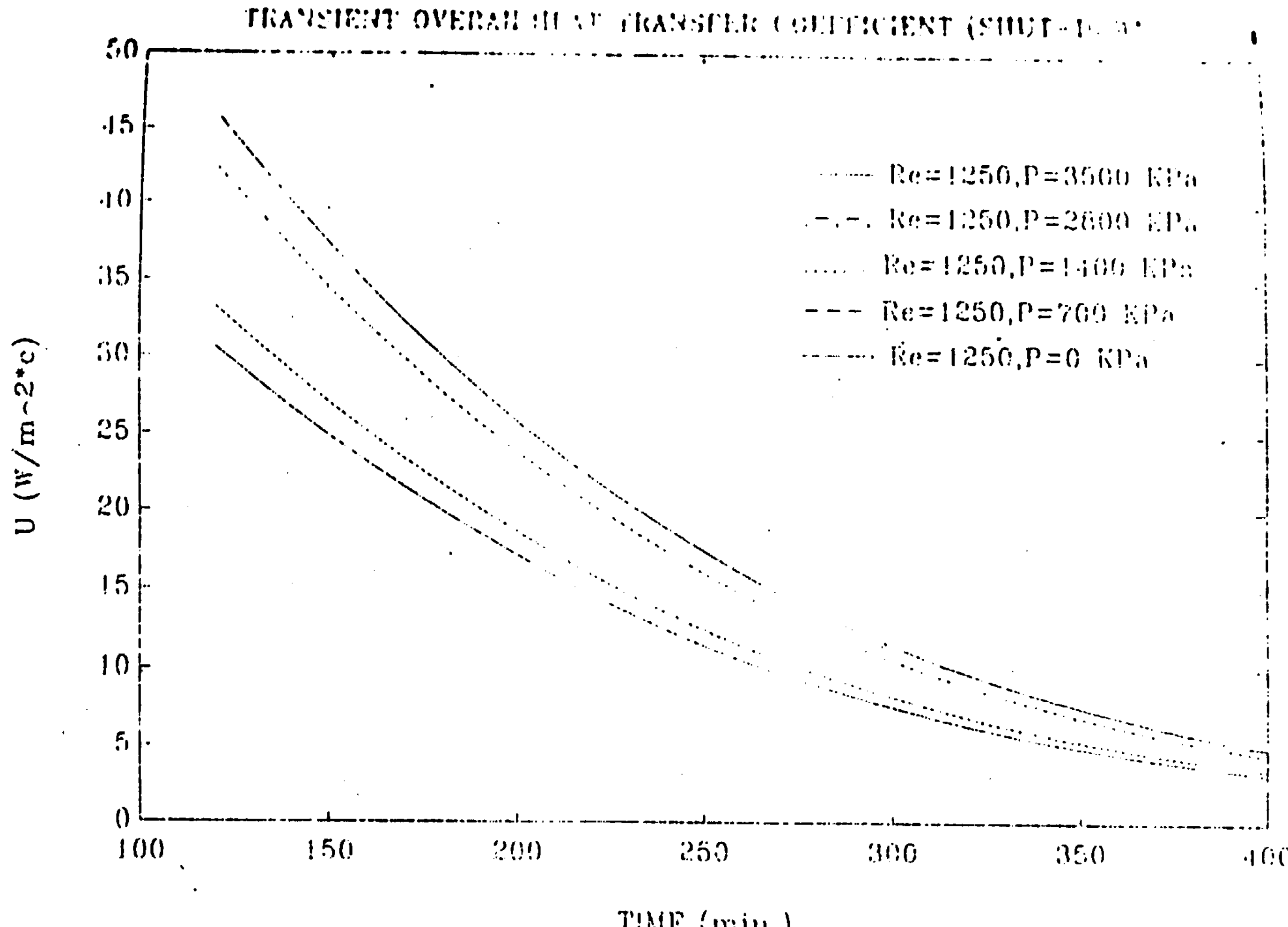


Figure 74. Analytical Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Water Coolant, Re = 1250).

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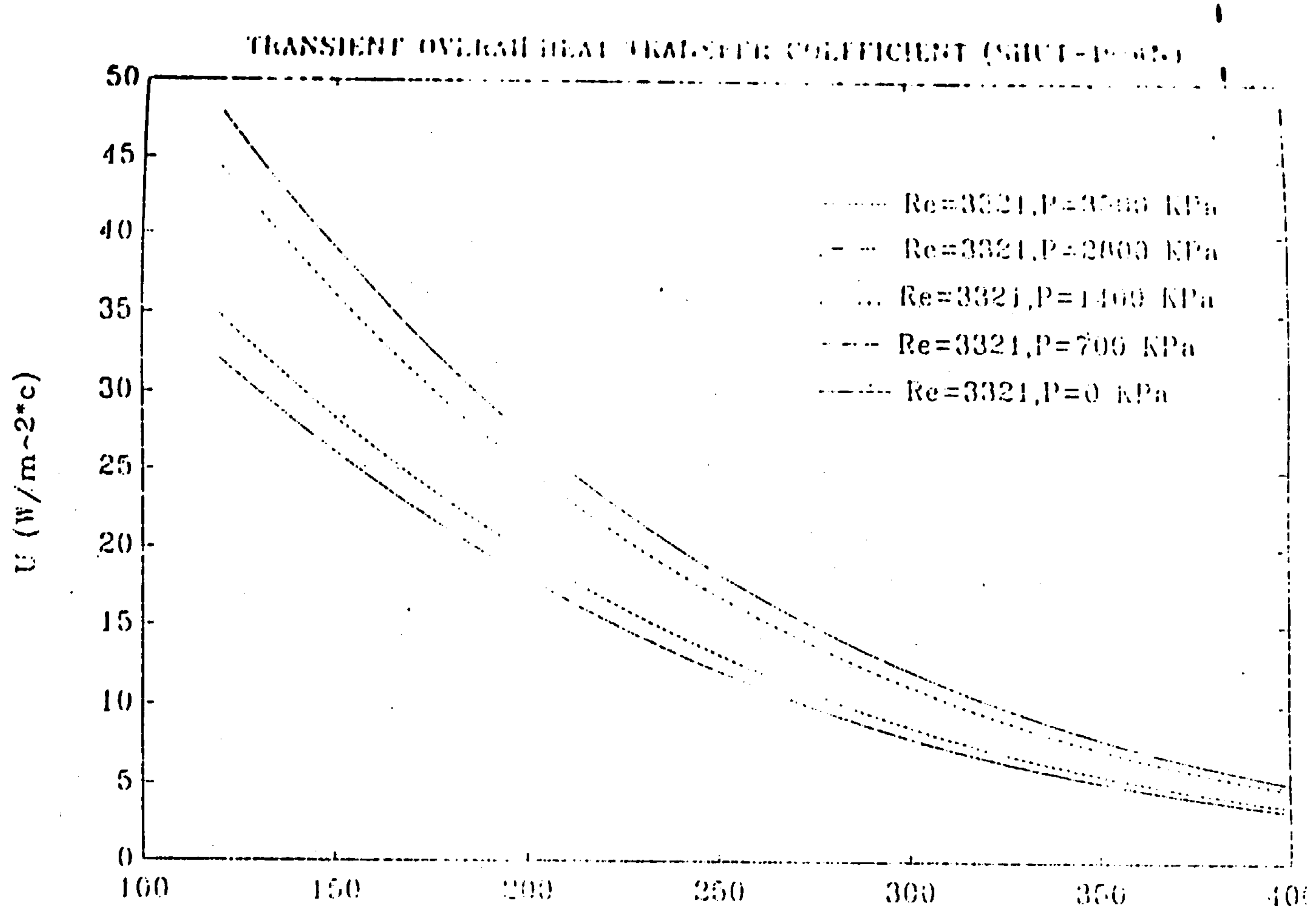


TIME (min.)

Figure 75. Analytical Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Water Coolant, Re = 3321).

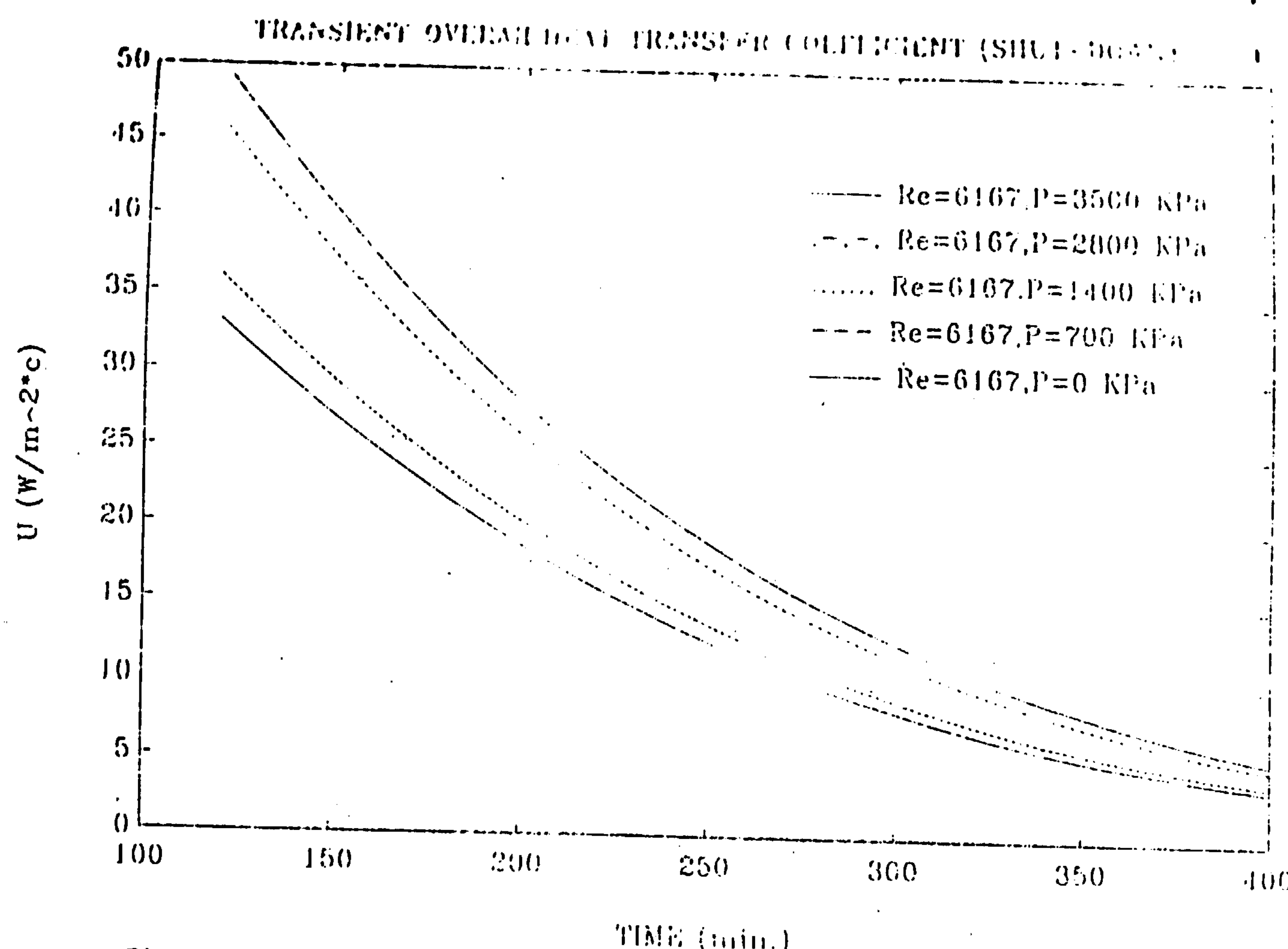


Figure 76. Analytical Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Water Coolant, Re = 6167).

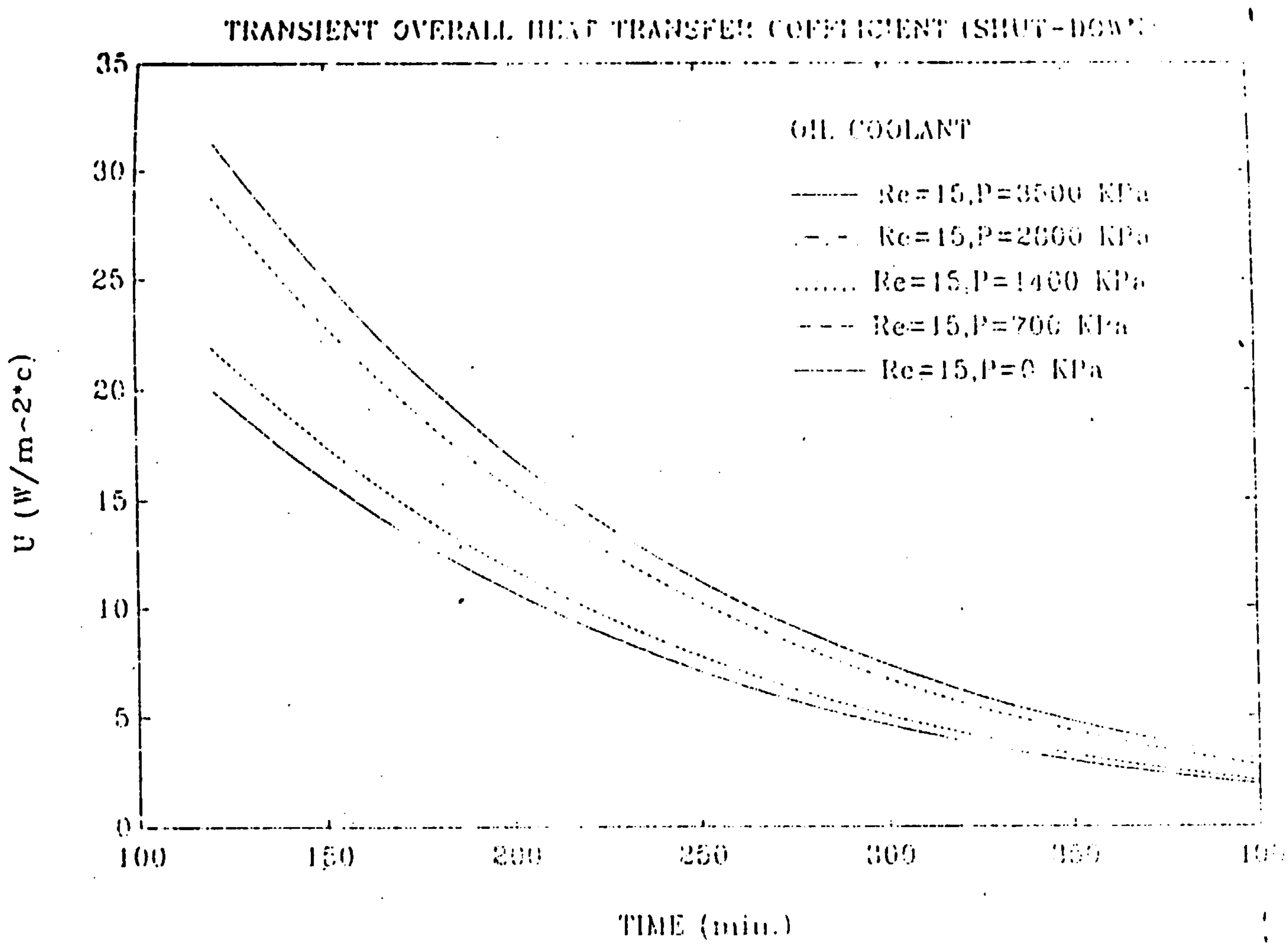


Figure 77. Analytical Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Oil Coolant, Re = 15).

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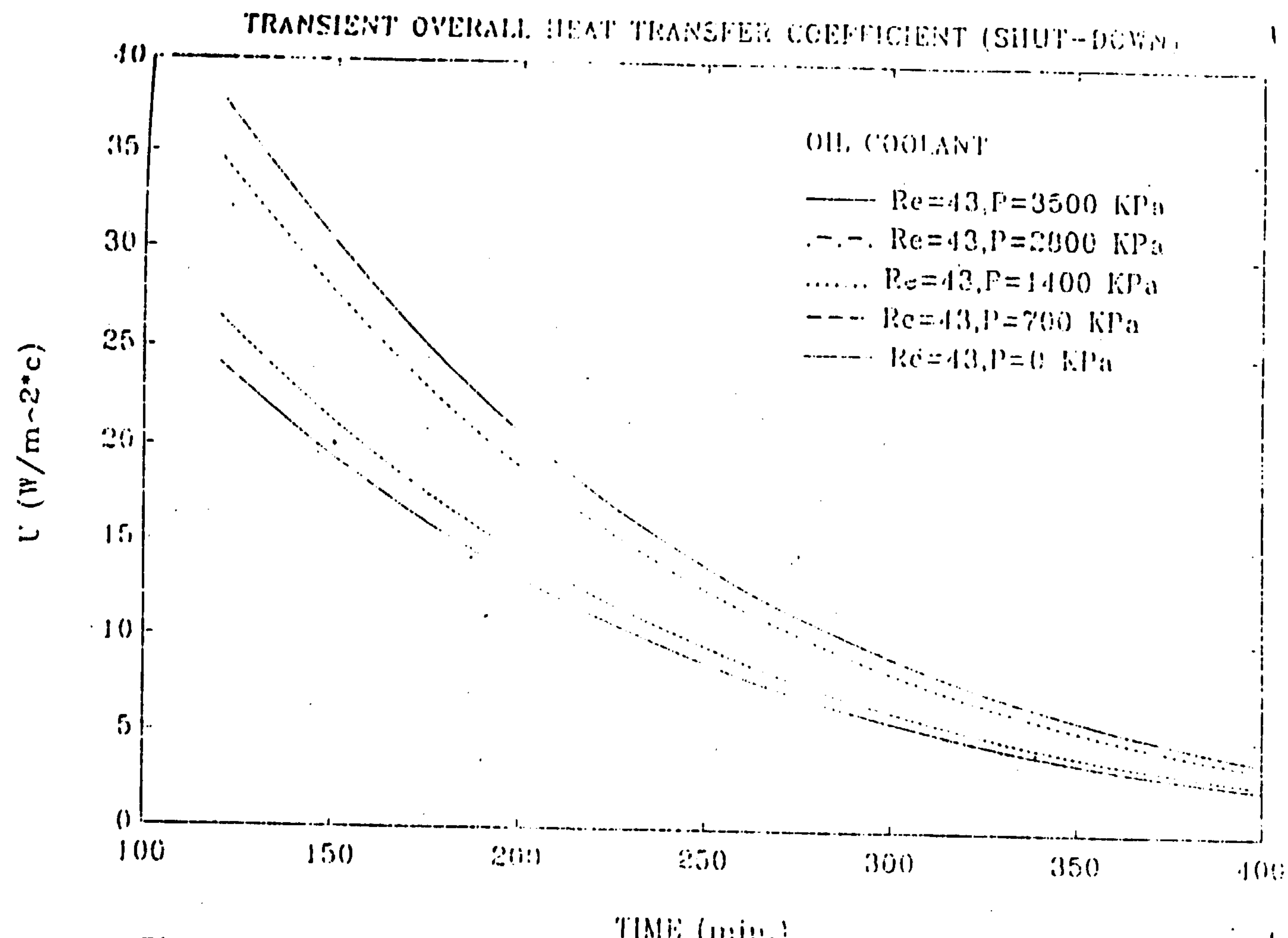



Figure 78. Analytical Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Oil Coolant, Re = 43).

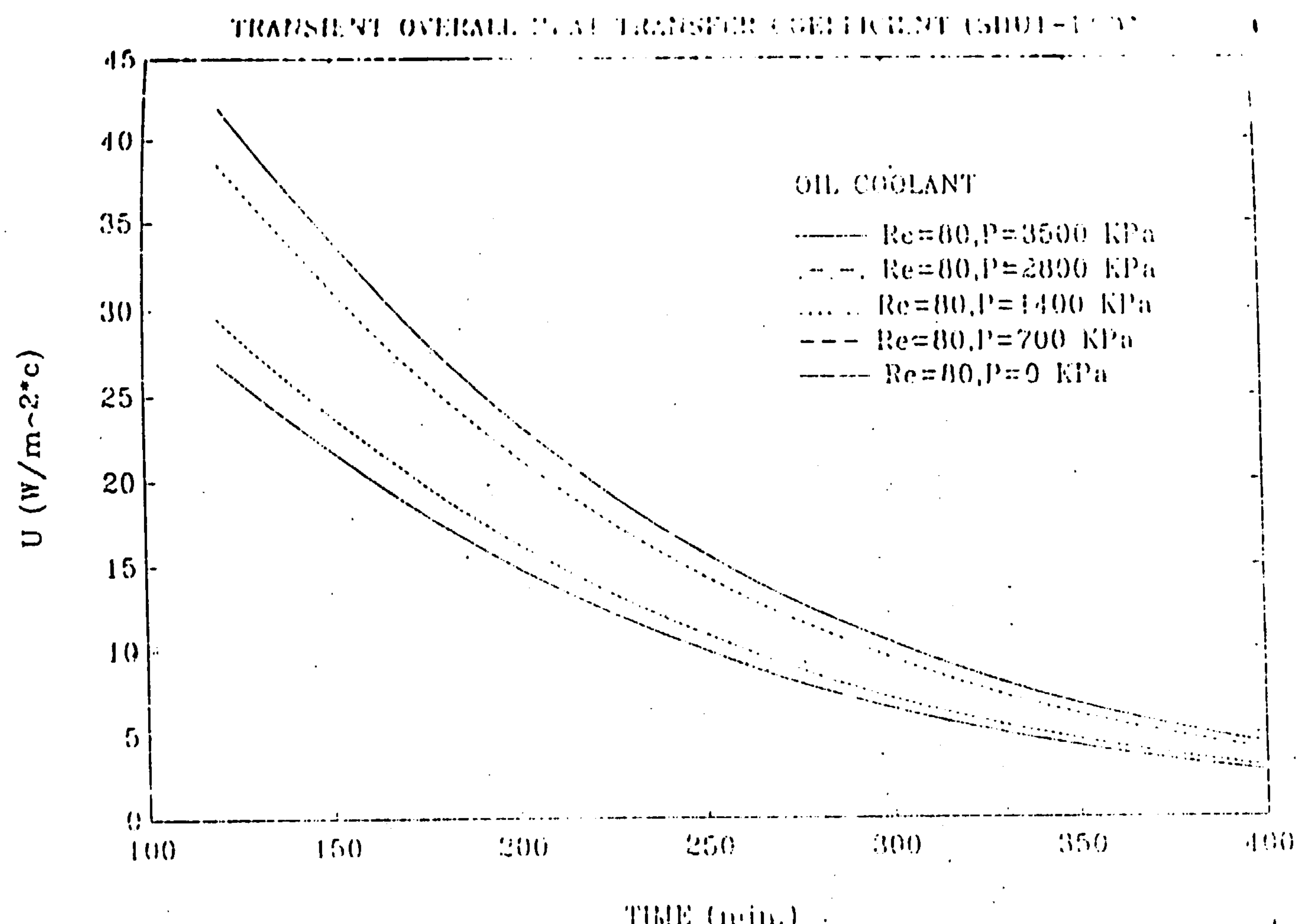



Figure 79. Analytical Transient Overall Heat Transfer Coefficient (Shut-Down Condition with Oil Coolant, Re = 80).

#### 4.3.2.3 Calculated Transient Overall Heat Transfer Coefficient

The transient overall heat transfer coefficient during a shut-down process was calculated using the same method defined in section 4.3.1.3.

(a) Water Coolant (Re = 1250 to Re = 6167)

Part of the calculated results are summarized by Figure 74 through Figure 76 which represents the minimum, average and maximuim water flow rates during a shut-down process.

(b) Oil Coolant (Re=15 to Re=80)

Figure 77 to Figure 79 demonstrates the change in the calculated overall heat transfer coefficient using the experimental calculations for three cases when oil was used as a coolant during a shut-down process.

## CHAPTER V

## TRANSIENT ELECTRODE TEMPERATURE DISTRIBUTION

The chemical reaction that takes place inside the phosphoric acid fuel cell results in generating thermal energy that approximately equals the electrical energy produced. In order to prevent temperature rise that leads to efficiency drop and high thermal stress, the excessive thermal energy is removed continously by heat transfer to the cooling plate and input gases.

It is extremely important to study the temperature profiles of the electrode to determine the thermal peaks locations and improve the cooling system design. In this chapter the transient temperature profiles developed from the experimental results will be compared with the theoretical results that were generated from the modified Fortran computer code developed originally by Alkasab and Lu [1] in their theoretical study. The internal heat generation produced by the chemical reaction can be simulated accurately by the heat generated by the resistance heating elements. The temperature profiles identify the areas with high thermal energy accumulation which is affected by the operation conditions such as the applied stack pressure, coolant flow rate and coolant fluid

properties. The transient isotherm were developed by monitoring the thermocouples readings located at 70 points in the fuel cell plate for the different considered operation conditions. The isotherms were drawn utilizing both the computer generated charts and the printed transient data.

In the following section, the transient experimental temperature profiles during start-up and shut-down processes will be analyzed for different operation conditions to examine the effect of the stack pressure, coolant flow rate and coolant properties on the cell model performance and the cooling system efficiency.

## 5.1 Experimental Temperature Profiles During Start-Up Process

### 5.1.1 The Effect of the Stack-Pressure on the Transient Temperature Distribution

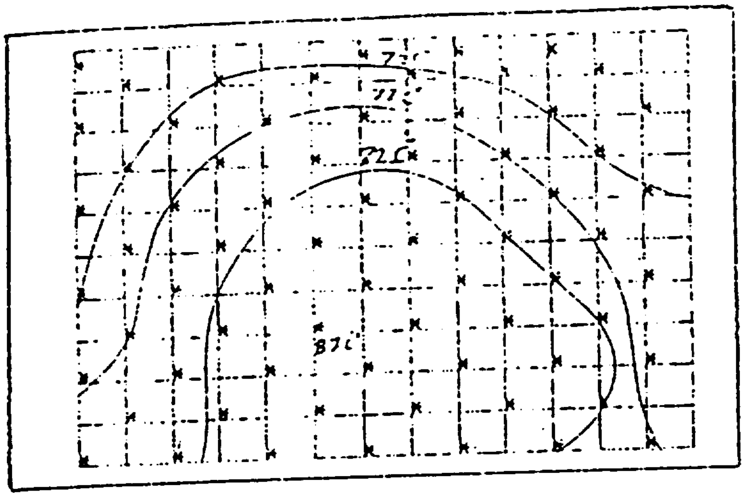
The effect of the stack pressure on the temperature distribution during a start-up process with a constant volumetric flow rate is demonstrated by Figure 80 through Figure 85 for water coolant and by Figure 87 through Figure 92 for oil coolant. The previous figures represent the generated isotherms that summarizes the thermocouple transient readings. Considering the first set for water, the coolant flow rate was kept constant at Re = 125°, while the stack pressure was changed from 0 Kpa to 3500 Kpa. From these figures, we can observe the increase of the temperature with respect to time until the steady state is

reached for any given coolant flow rate and stack pressure. The highest temperature zone location is slightly off the center due to the configuration of the cooling system. With higher stack pressure two effects on the transient electrode temperature distribution were noticed.

(a) Higher transient average electrode temperature with higher applied stack pressure approximately $3.064*10^3$ °C/KPa as shown in Figure 86. Considering the most extreme case when water was used as a coolant, with minimum flow rate, the peak electrode temperature as exhibited by Figures 80 to 82 when the applied stack pressure was (0 KPa), increased from 87.1°C to 185.3°C during the considered time intervals. On the other hand, when the applied stack pressure was increased to 3500 KPa the peak electrode temperature increased from 92°C to 189°C before reaching the steady state operation condition. The average transient electrode temperature, when the applied pressure was 3500 KPa, went up from 64.8 °C to 129.3 °C with Re=1250 as shown by Figure 86. The reason for this temperature increase will be explained in Chapter VII.

Similar transient electrode temperature distributions were noticed when oil was used as the cooling fluid for different flow rates, refer to Figures 87 to 93. However, in general the peak and average transient electrode temperatures were higher for oil than those for water as

Instantaneous Electrode Temperature Profile



Re - 1250

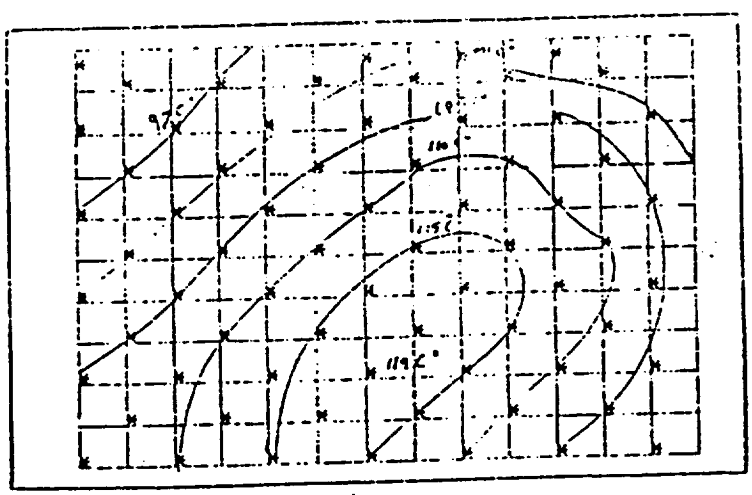
P - 0 (KPa)

E.E. - 1500 (W/m^2)

Coolant Fluid : water

Figure 80. Instantaneous Temperature Profiles During Start-Ups (Water Coolant, P=0 KPa, Re=1250, E.E.=1500 $w/m^2$).

Instantaneous Electrode Temperature Profile



Re - 1250

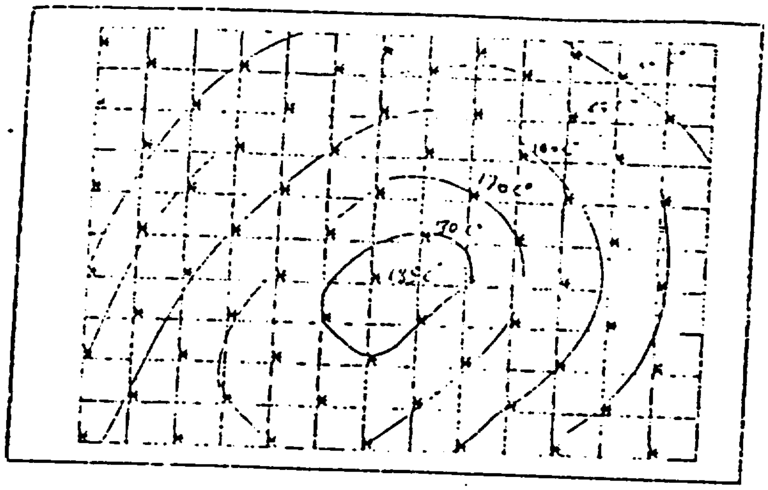
P - 0 (KPa)

E.E. - 2250 (W/m^2)

Coolant Fluid : water

Figure 81. Instantaneous Temperature Profiles During Start-Ups (Water Coolant, P=0 KPa, Re=1250, E.E.=2250 $w/m^2$).

Instantaneous Electrode Temperature Profile



Re - 1250

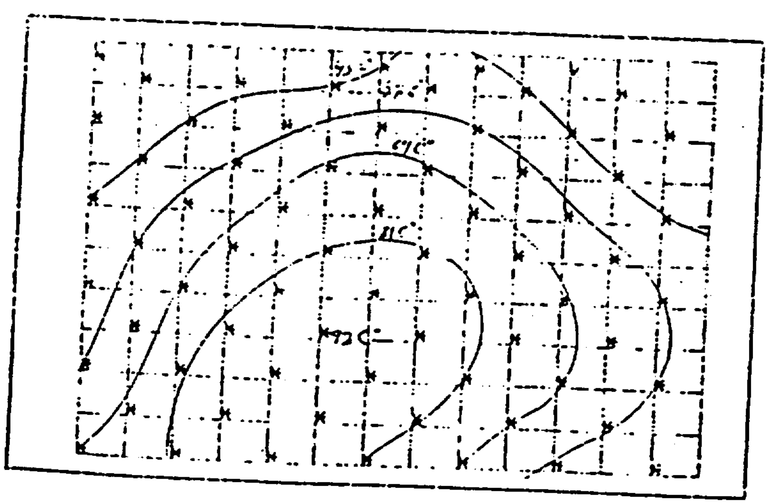
P - 0 (KPa)

E.E. - 3000 (W/m^2)

Coolant Fluid : water

Figure 82. Instantaneous Temperature Profiles During Start-Ups (Water Coolant, P=0 KPa, Re=1250, E.E.=3000 $w/m^2$).

Instantaneous Electrode Temperature Profile



Re - 1250

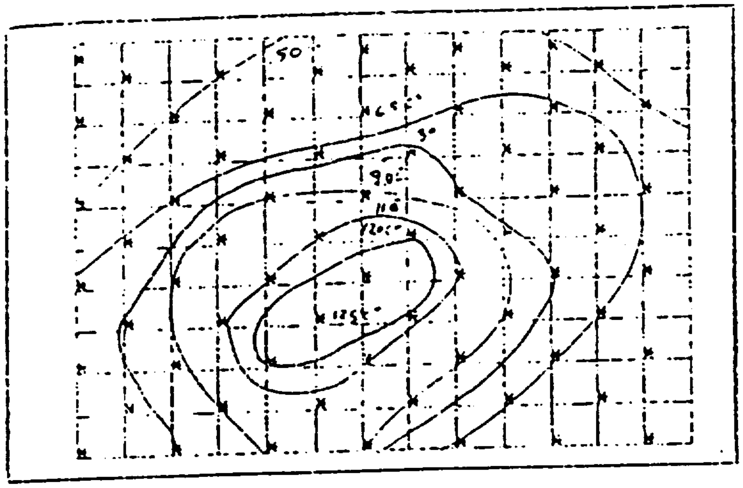
P - 3500 (KPa)

E.E. - 1500 (W/m^2)

Coolant Fluid : water

Figure 83. Instantaneous Temperature Profiles During Start-Ups (Water Coolant, P=3500 KPa, Re=1250, E.E.= 1500 $w/m^2$).

Instantaneous Electrode Temperature Profile



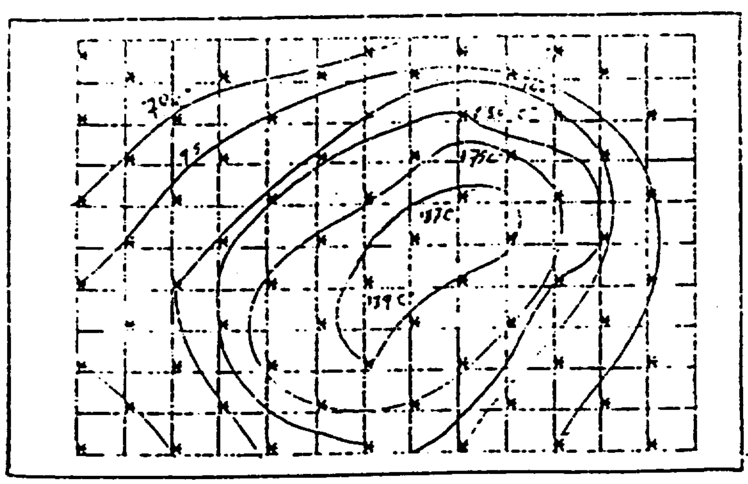
Re - 1250 Coolant Fluid : water

P - 3500 (KPa)

E.E. - 2250 (W/m^2)

Figure 84. Instantaneous Temperature Profiles During Start-Ups (Water Coolant, P=3500 KPa, Re=1250, E.E.=2250 w/m$^2$).

Instantaneous Electrode Temperature Profile



Re - 1250 Coolant Fluid : water

P - 3500 (KPa)

E.E. - 3000 (W/m^2)

Figure 85. Instantaneous Temperature Profiles During Start-Ups (Water Coolant, P=3500 KPa, Re=1250, E.E.=3000 w/m$^2$).

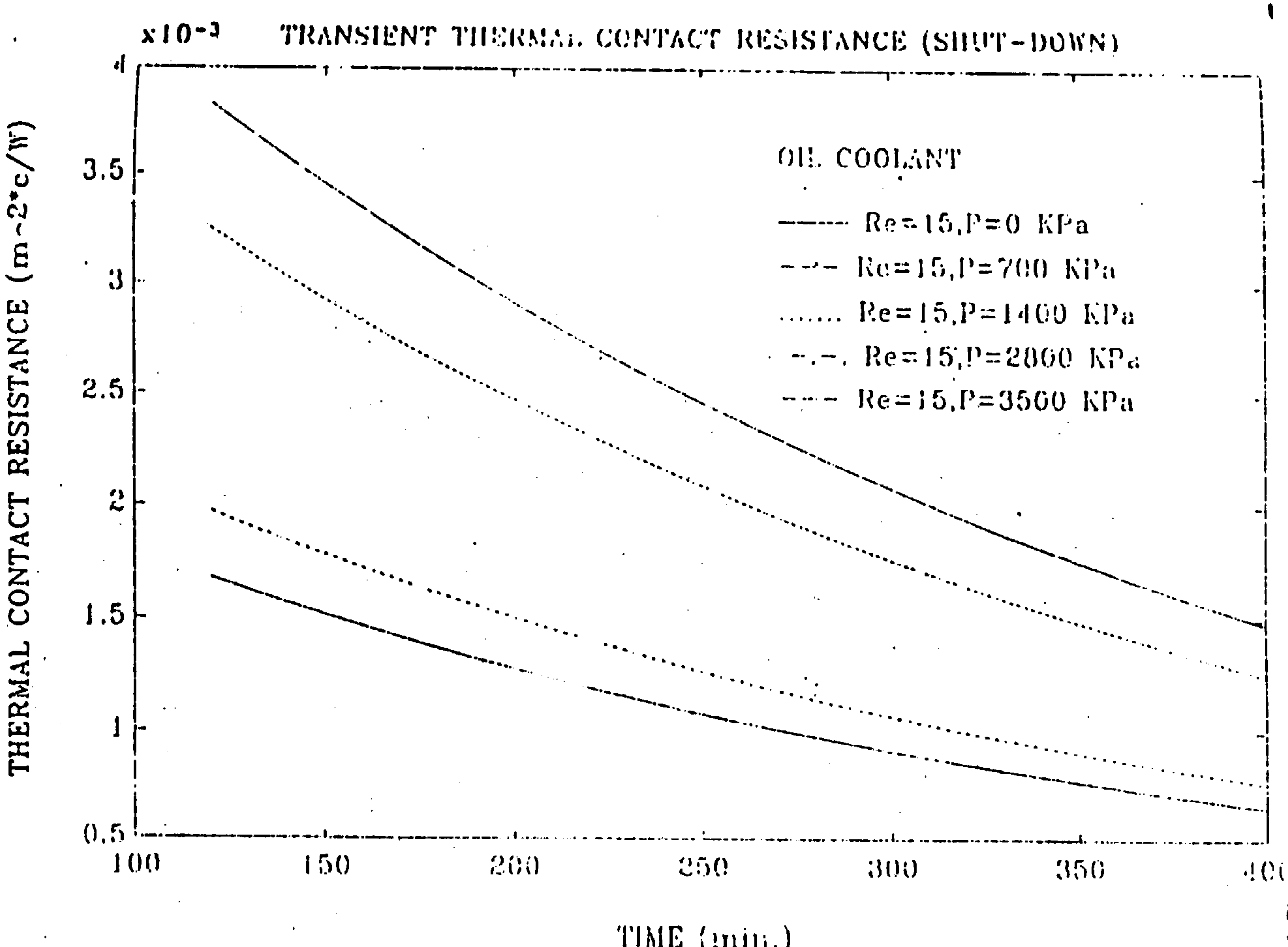



Figure 65. Analytical Transient Thermal Contact Resistance (Shut-Down Condition with Oil Coolant, Re = 15).

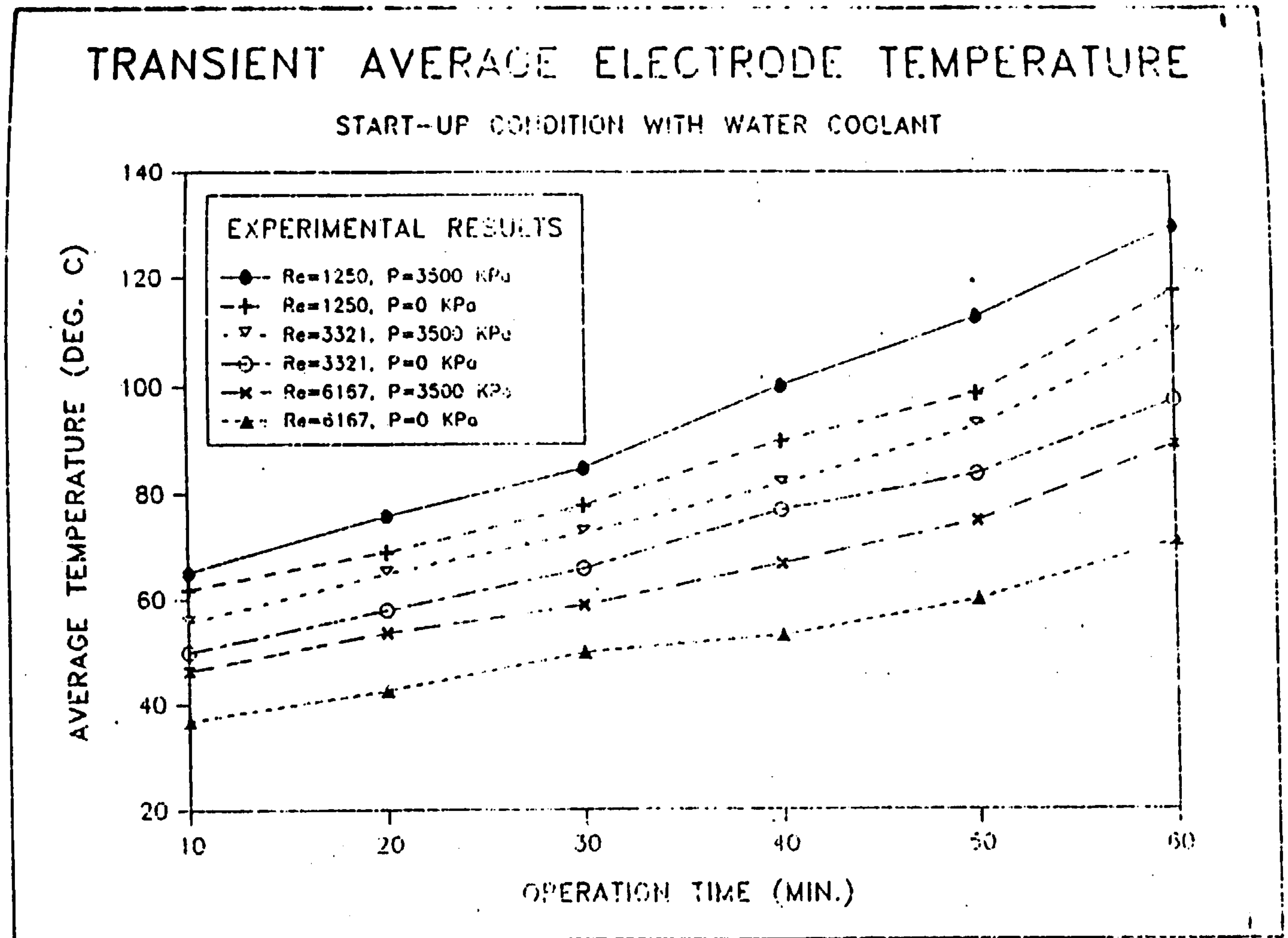



Figure 86. Experimental Transient Average Electrode Temperature During Start-Ups with Water Coolant.

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demonstrated by Figure 97 which shows the variation of the experimental transient average temperature. The average transient electrode temperature increase per unit of applied pressure was approximately $2.131 * 10^{-3}$ °C/KPa. These results were unexpected. Higher heat transfer rates to the coolant should decrease the average surface temperature of the cathode plate.

(b) More uniform temperature distribution: the transient isotherms temperature difference decreases and that is basically due to enhancing the surface contacts because of increasing the clamping pressure which causes reducing the thermal contact resistance. This in turn will result in a more even and symmetrical temperature distribution and reduce the existence of high number of thermal peaks. These observations were common for both coolants used.

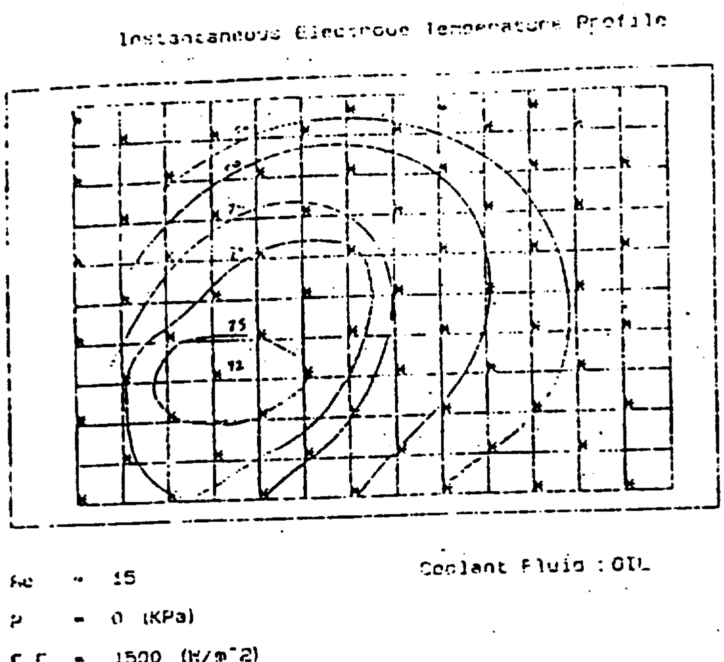



Figure 87. Instantaneous Temperature Profiles During Start-Ups (Oil Coolant, P=0 KPa, Re=15, E.E.=1500 w/m$^2$).

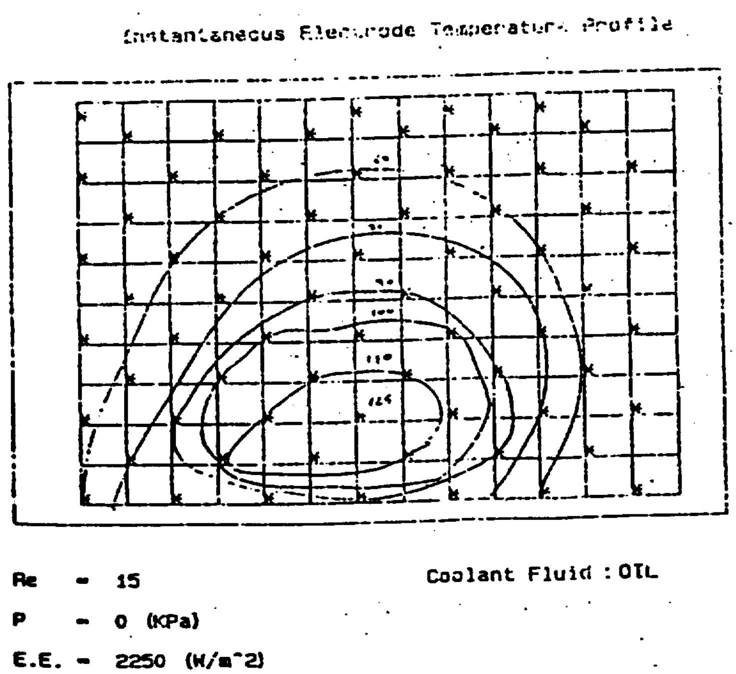





Figure 88. Instantaneous Temperature Profiles During Start-Ups (Oil Coolant, P=0 KPa, Re=15. E.E.=2250 w/m$^2$).

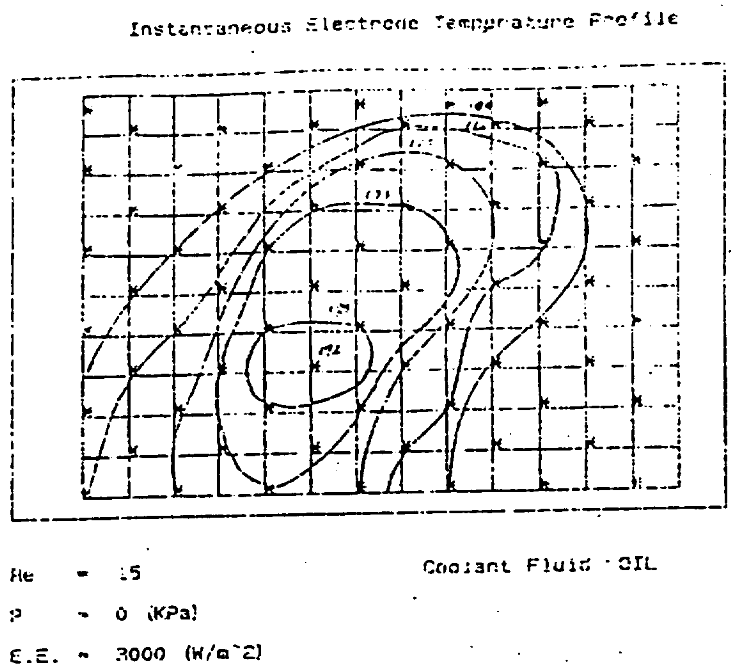



Figure 89. Instantaneous Temperature Profiles During Start-Ups (Oil Coolant, P=0 KPa, Re=15, E.E.=3000 w/m$^2$).

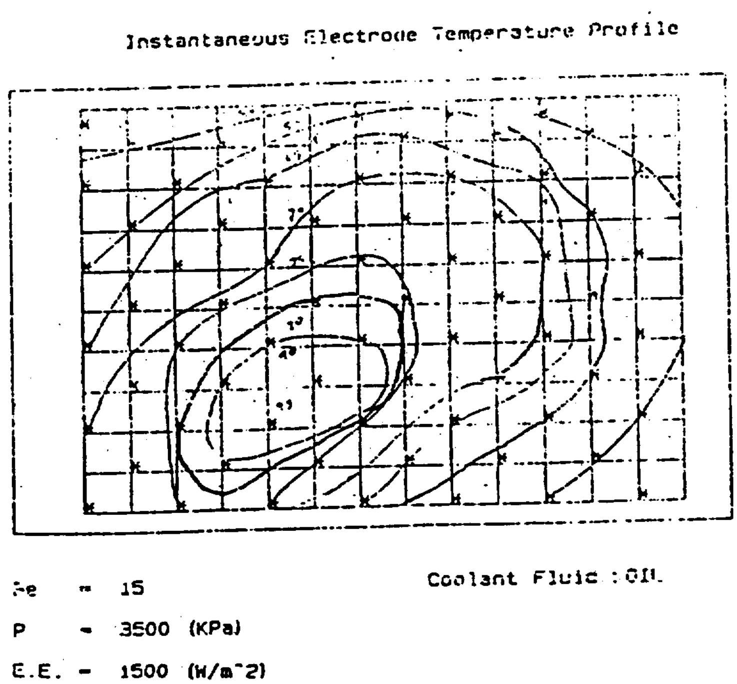



Figure 90. Instantaneous Temperature Profiles During Start-Ups (Oil Coolant, p=3500 KPa, Re=15, E.E.=1500 w/m$^2$).

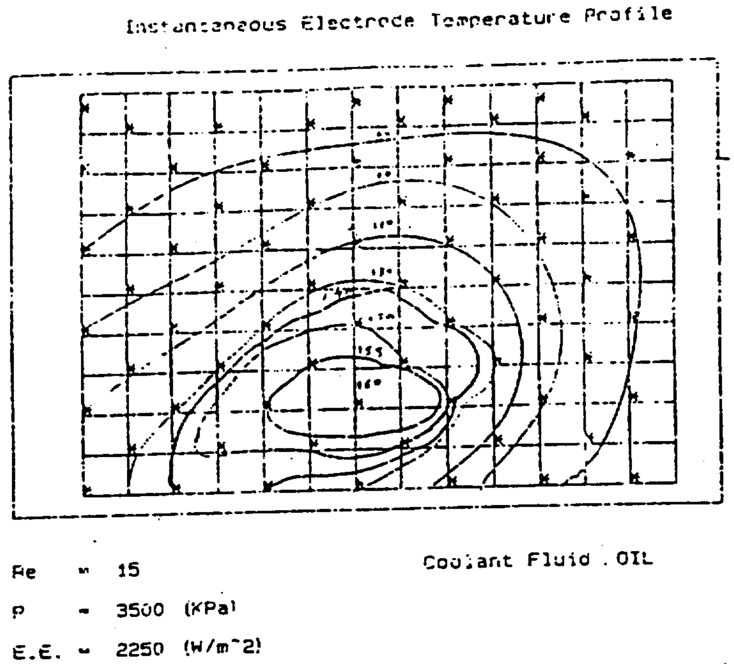



Figure 91. Instantaneous Temperature Profiles During Start-Ups (Oil Coolant, p=3500 KPa, Re=15, E.E.=2250 $w/m^2$).

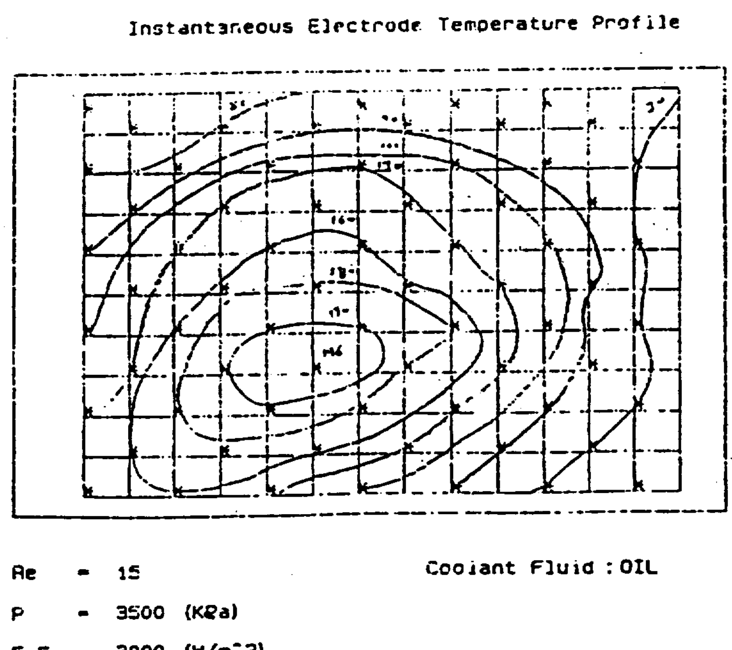



Figure 92. Instantaneous Temperature Profiles During Start-Ups (Oil Coolant, p=3500 KPa, Re=15, E.E.=3000 $w/m^2$).

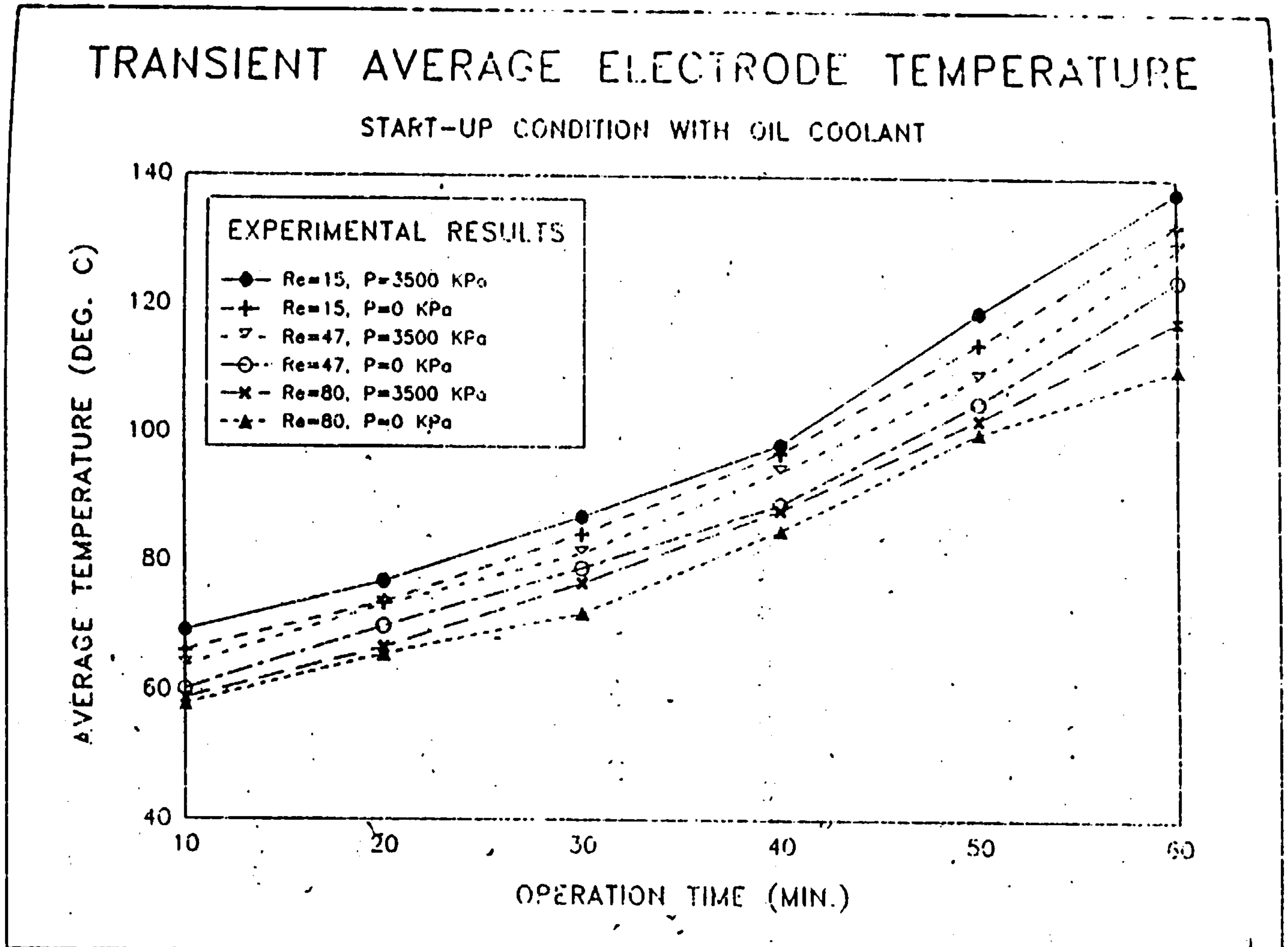



Figure 93. Experimental Transient Average Electrode Temperature During Start-Ups with Oil Coolant.

### 5.1.2 The Effect of the Coolant Fluid Flow Rate on the Transient Temperature Distribution

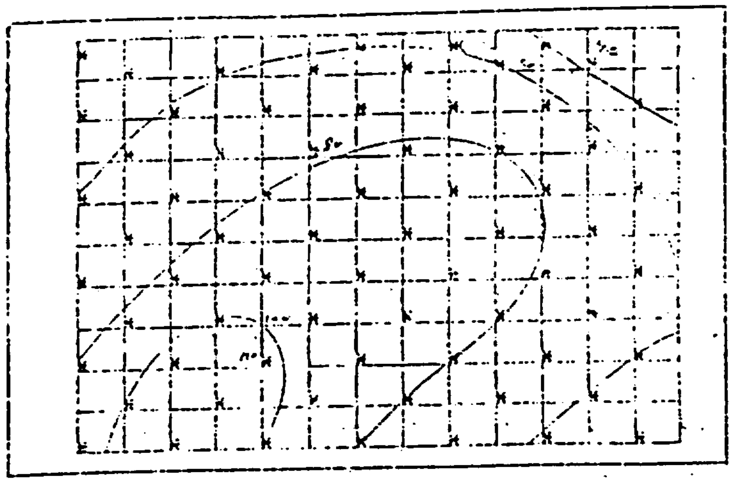
The other parameter, beside the stack pressure, that will affect the performance of the fuel cell is the mass flow rate of the cooling system and the thermophysical properties of the fluid. This section was devoted to examine the influence of those two parameters on the transient temperature profiles, transient fuel cell average temperature and peak electrode temperature when the stack pressure is kept constant throughout the considered experimental time intervals.

Referring to Figure 94 through Figure 96, the following can be observed for the water coolant case:

(a) The cell peak electrode temperature increased from 87.1 °C to 185.3 °C when the Re number was 1250 and from 84.3°C to 140°C when Re = 6167 with an applied stack pressure of 0 KPa.

(b) Lower transient average electrode temperature were noticed for both fluids with higher mass flow rate as shown in Figure 101 for Re number. For example comparing between the test done using water coolant with Re=6167 using (0 KPa) applied pressure and that with Re = 1250 using the same applied pressure, the average temperature went up from 37.2 °C to 68.4°C in the first test while the raise in the second case was from 63.3°C to 118.4 °C.

Instantaneous Electrode Temperature Profile



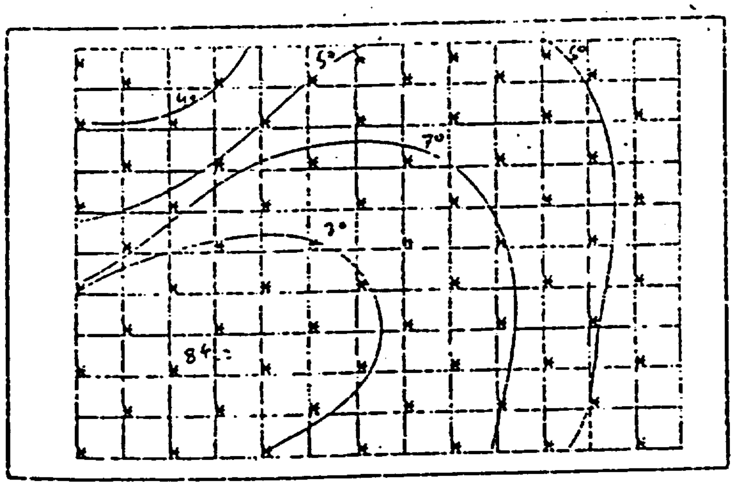
Re - 6167 Coolant Fluid : water

P - 0 (KPa)

E.E. - 2250 (W/m^2)

Figure 95. Instantaneous Temperature Profiles During Start-Up (Water Coolant, P=0 KPa, Re=6167 E.E.=2250 w/m$^2$).

Instantaneous Electrode Temperature Profile



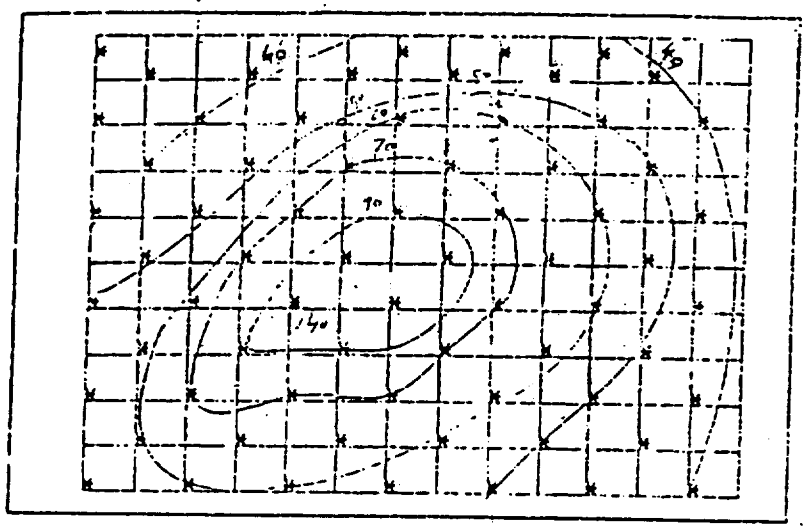
Re - 6167 Coolant Fluid : water

P - 0 (KPa)

E.E. - 1500 (W/m^2)

Figure 94. Instantaneous Temperature Profiles During Start-Up (Water Coolant, P=0 KPa, Re=6167, E.E.=1500 w/m$^2$).

Instantaneous Electrode Temperature Profile




Re = 6157 Coolant Fluid : water

P = 0 (KPa)

E.E. = 3000 (W/m^2)

Figure 96. Instantaneous Temperature Profiles During Start-Up (Water Coolant, P=0 KPa, Re=6167, E.E.=3000 w/m$^2$).

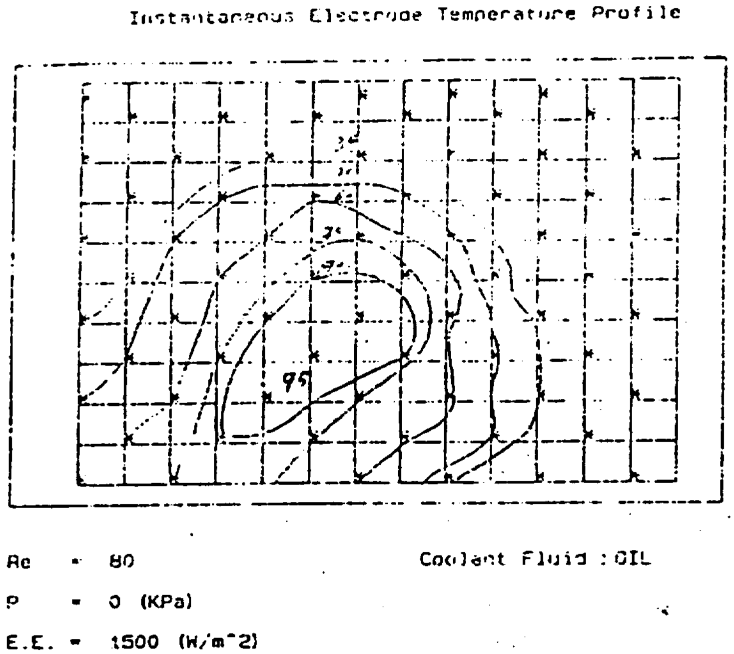



Figure 97. Instantaneous Temperature Profiles During Start-Up (Oil Coolant, P=0 KPa, Re=80, E.E.=1500 $w/m^2$).

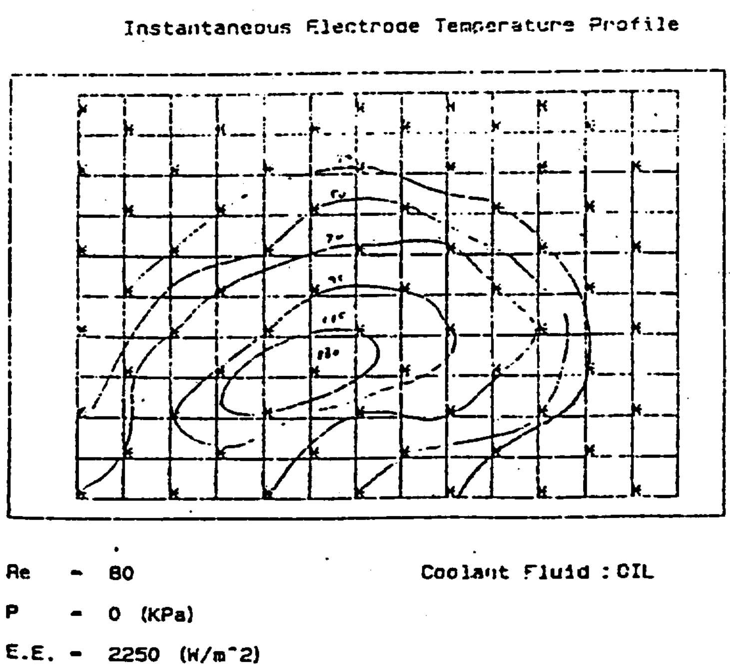
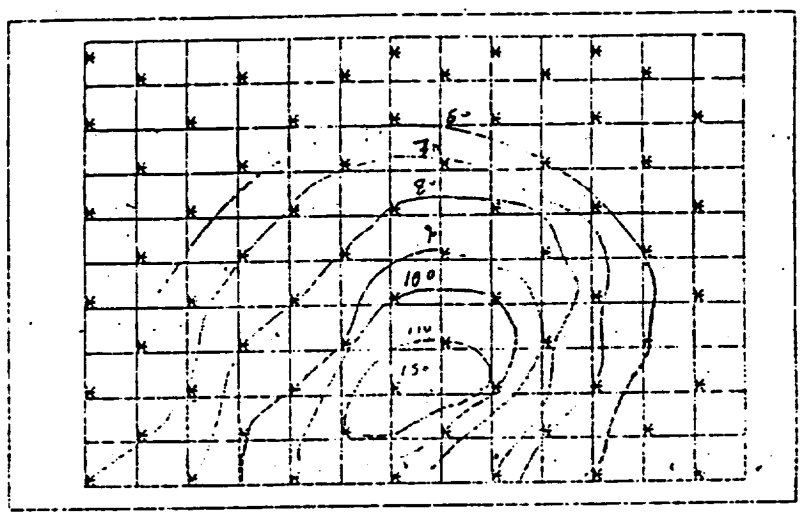



Figure 98. Instantaneous Temperature Profiles During Start-Up (Oil Coolant, P=0 KPa, Re=80, E.E.=2250 $w/m^2$).

Instantaneous Electrode Temperature Profile



Re = 80 Coolant Fluid : OIL

P = 0 (KPa)

E.E. = 3000 (W/m^2)

Figure 99. Instantaneous Temperature Profiles During Start-Up (Oil Coolant, P=0 KPa, Re=80, E.E.=3000 w/m$^2$).

(c) By comparing Figures 80 to 82 and Figures 94 to 96, it can be noticed that the transient temperature profiles propagation rate decreased with increasing the mass flow rate.

On the other hand, when oil was used as a coolant similar observations were noticed with higher volumetric flow rates and constant applied pressure as shown by Figure 97 to Figure 99 which summarizes the effect of the coolant flow rate on the temperature profiles for Re = 15, P = 0KPa and Re =80, P = 0 KPa. Referring to Figure 93, the variation of the average temperature for part of the experimental results are summarized as a function of time. The transient average electrode temperature decreased with high coolant volumetric flow rates remarkably. Also, the decrease in the transient peak electrode temperature was very obvious with higher Re numbers.

## 5.2 Experimental Temperature Profiles During Shut-Down Process

### 5.2.1 The Effect of Stack Pressure on the Transient Temperature Distribution

During a shut-down process similar observations were noticed for both working fluids when the effect of the stack pressure is considered while keeping the mass flow rate constant. The variation of the average transient electrode temperature is exhibited by Figure 100 and Figure 101 for both coolant. The electrode of temperature drop rate in the electrode was slower with higher pressure. Also the average increase in the temperature due to increasing the pressure was $2.893 * 10^{-3}$ and $2.011 * 10^{-3}$ °C/KPa for water and oil respectively. On the other hand, the temperature profiles were more uniform than the start-up process as demonstrated by Figure 102 through Figure 107 for water coolant for the whole testing period.

### 5.2.2 The Effect of the Coolant Fluid Flow Rate on the Transient Temperature Distribution

The higher coolant mass flow rate has increased the electrode temperature drop rate when the pressure is kept constant. Also, the peak electrode temperature was reduced significantly with a higher Re number for both fluids. In addition, the transient isotherms temperature differential decreased dramatically when the mass flow rates were increased.

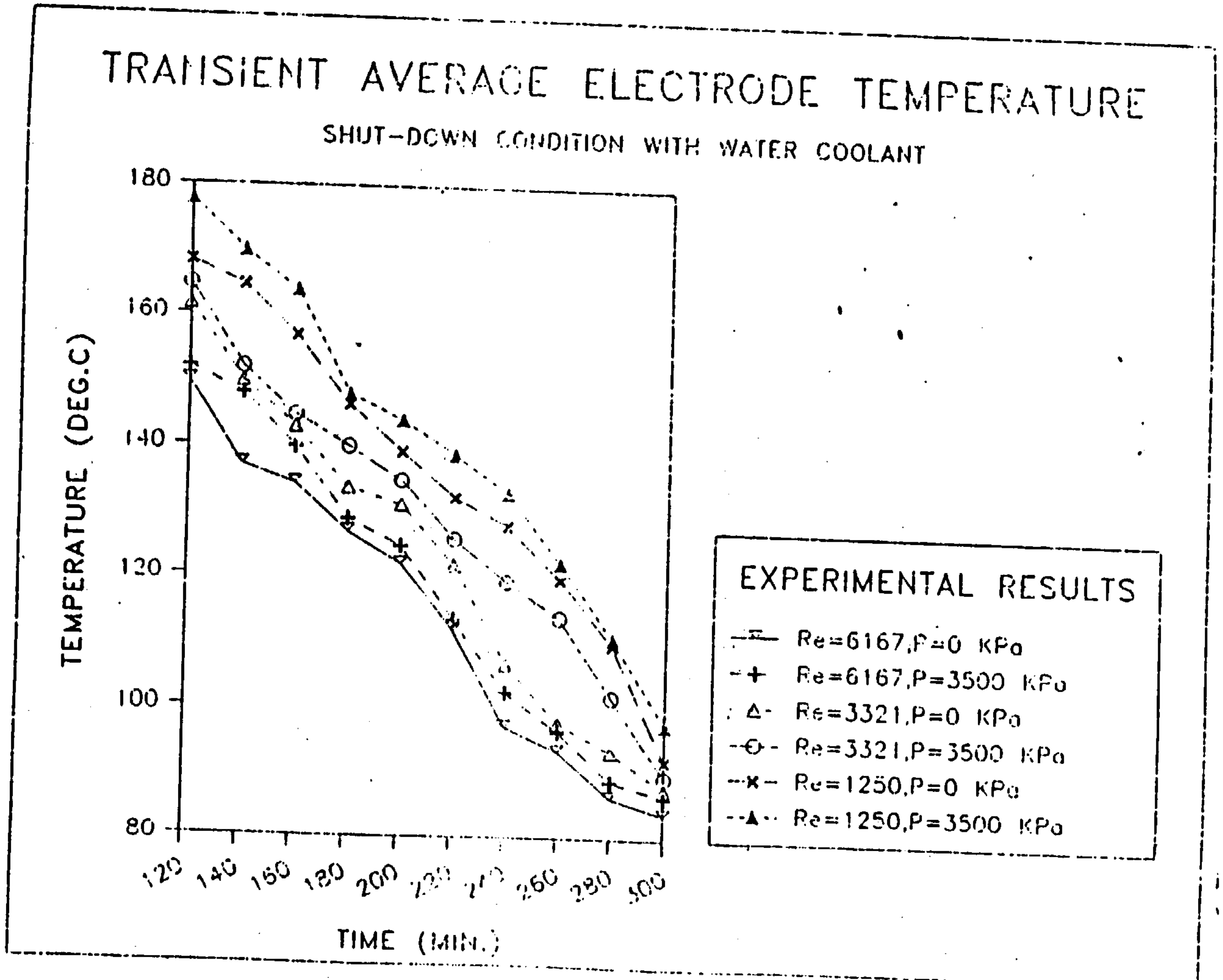



Figure 100. Experimental Average Electrode Temperature During Shut-Down. Using Water Coolant.

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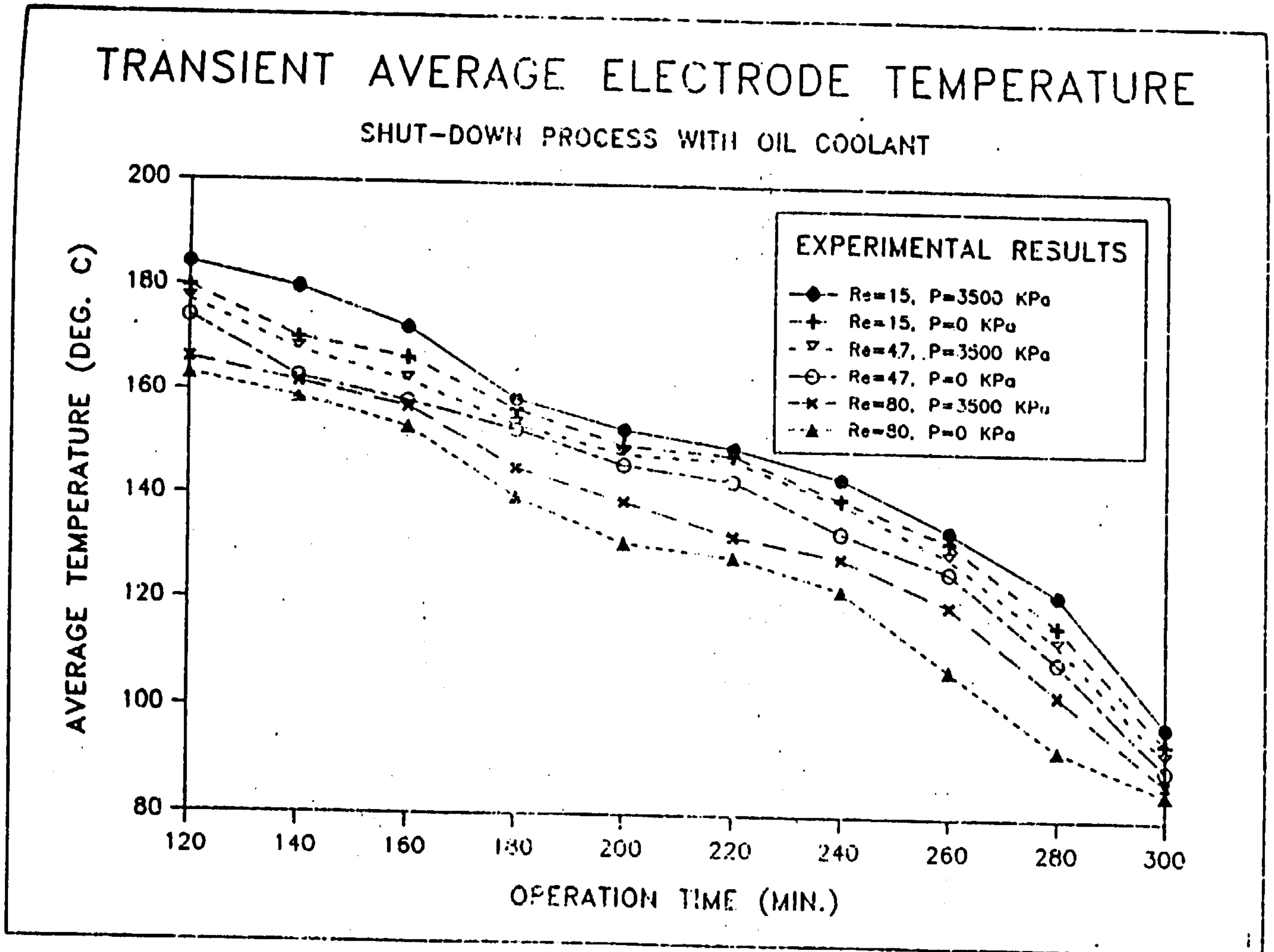
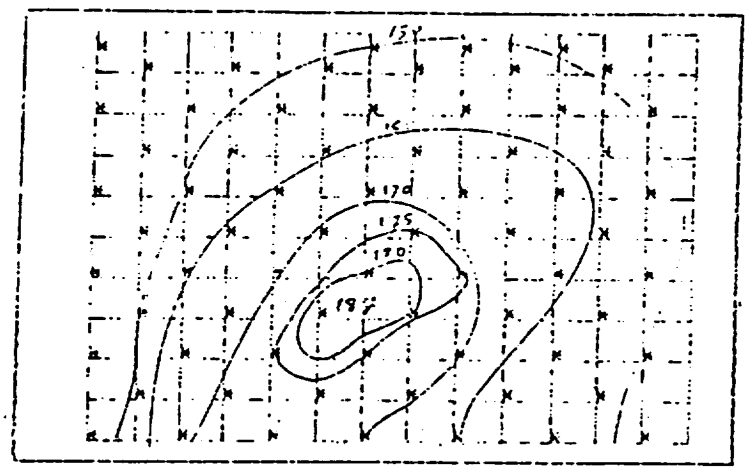



Figure 101. Experimental Average Electrode Temperature During Shut-Down Using Oil Coolant.

Instantaneous Electrode Temperature Profile



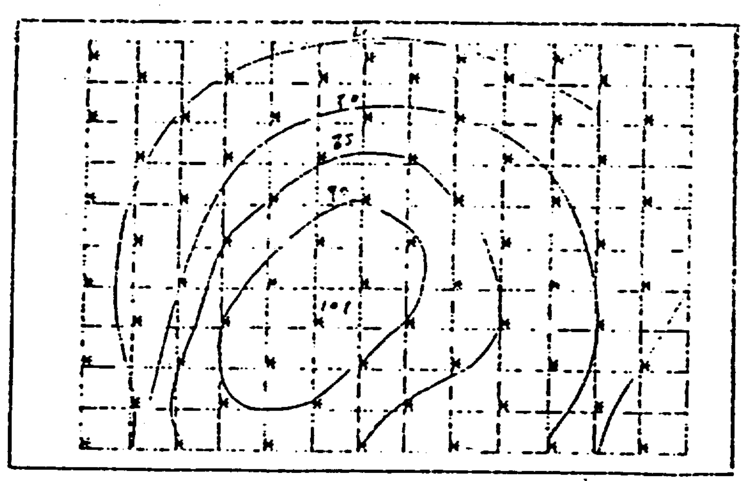
Re - 1250 Coolant Fluid : water

P - 0 (KPa)

E.E. - 2250 (W/m^2)

Figure 102. Instantaneous Electrode Temperature Profiles During Shut-Down Process (Water Coolant, P=0 KPa, Re=1250, E.E.=2250 w/m$^2$).

Instantaneous Electrode Temperature Profile



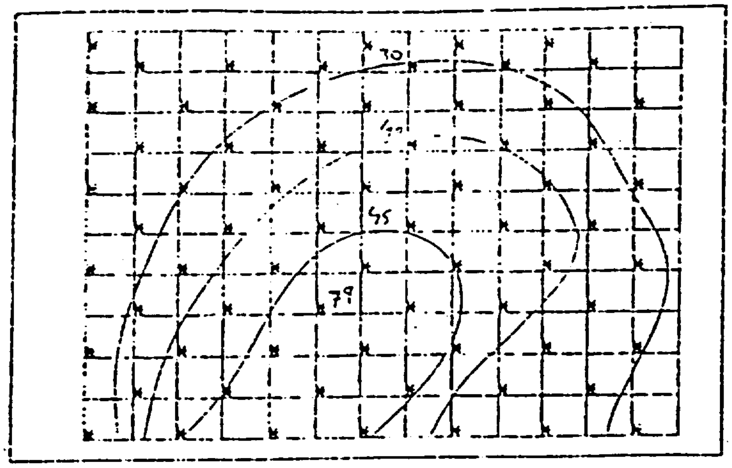
Re - 1250 Coolant Fluid : water

P - 0 (KPa)

E E. - 1500 (W/m^2)

Figure 103. Instantaneous Electrode Temperature Profiles During Shut-Down Process (Water Coolant, P=0 KPa, Re=1250, E.E.=1500 w/m$^2$).

Instantaneous Electrode Temperature Profile



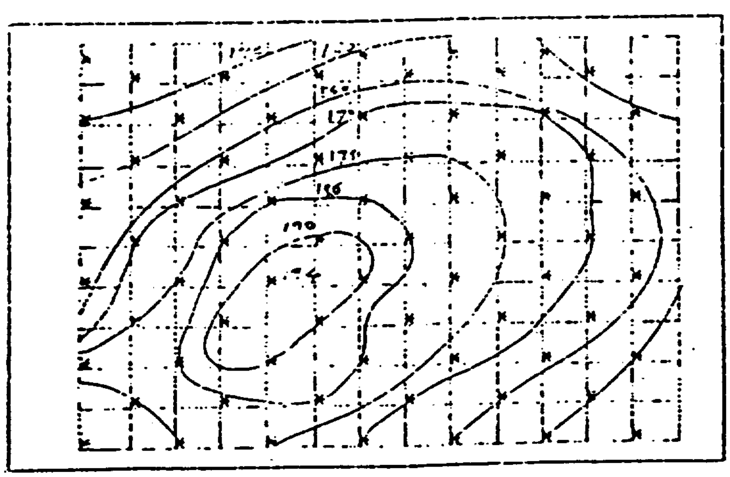

Re - 1250 Coolant Fluid : water

P - 0 (KPa)

E.E. - 0 (W/m^2)

Figure 104. Instantaneous Electrode Temperature Profiles During Shut-Down Process (Water Coolant, P=0 KPa, Re=1250, E.E.=0 $w/m^2$).

Instantaneous Electrode Temperature Profile



Re - 1250 Coolant Fluid : water

P - 3500 (KPa)

E.E. - 2250 (W/m^2)

Figure 105. Instantaneous Electrode Temperature Profiles During Shut-Down Process (Water Coolant, P=3500 KPa, Re=1250, E.E.= 2250 $w/m^2$).

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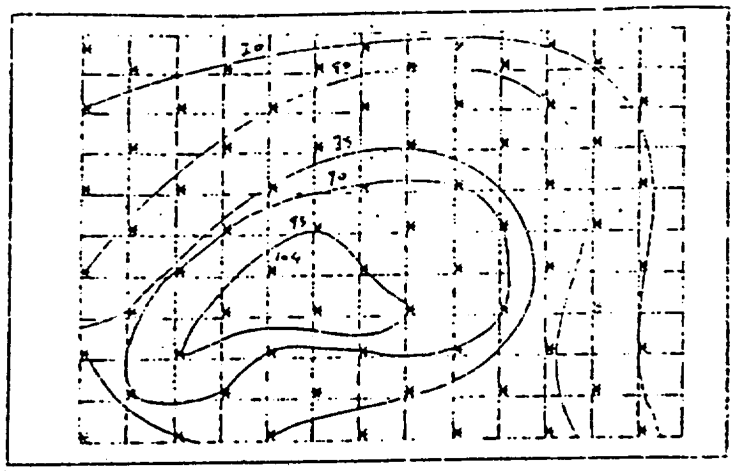
Instantaneous Electrode Temperature Profile



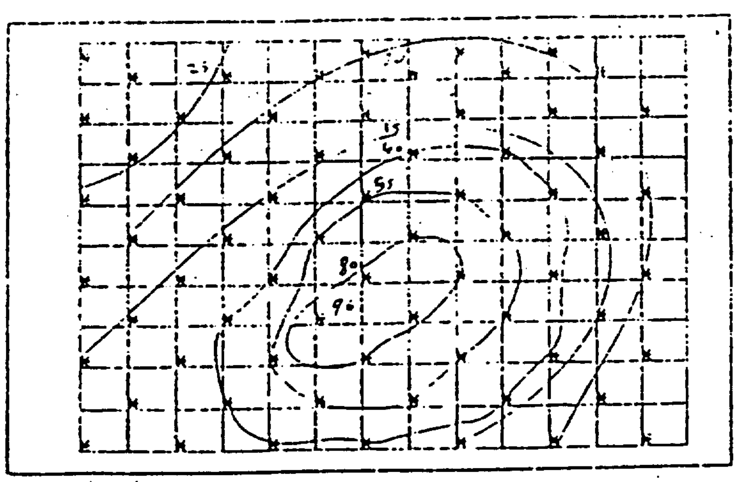
Re - 1250 Coolant Fluid : water

P - 3500 (KPa)

E.E. - 1500 (W/m^2)

Figure 106. Instantaneous Electrode Temperature Profiles During Shut-Down Process (Water Coolant, P=3500 KPa, Re=1250, E.E.=1500 w/m$^2$).

Instantaneous Electrode Temperature Profile



Re - 1250 Coolant Fluid : water

P - 3500 (KPa)

E.E. - 0 (W/m^2)

Figure 107. Instantaneous Electrode Temperature Profiles During Shut-Down Process (Water Coolant, P=3500 KPa, Re=1250, E.E.=0 w/m$^2$).

## 5.3 Theoretical Analysis of the Transient Temperature Distribution

In this section the theoretical analysis developed by Alkasab and Lu [1] was modified for the transient operation condition considered with incompressible cooling fluids. The previous analysis considered the PAFC shown in Figure 108 where the stack consists of a matrix of five cells between each cooling plate sandwich.

The energy balance equation used represents the contribution of fuel cell, cooling plate, process air and coolant in the heat exchange during a transient process. The following assumptions were considered when modifying that model:

(a) The total thermal resistance of the system is dependent on the applied stack pressure, i.e. ($K_x$) is not constant and will be modified using the experimental correlations for the thermal contact resistance developed in the previous chapter.

(b) A symmetrical behavior of identical halves throughout the fuel cell stack.

(c) One-phase flow.

(d) Incompressible working fluids.

(e) Constant processing and cooling fluid specific heat and densities values during the considered time intervals.

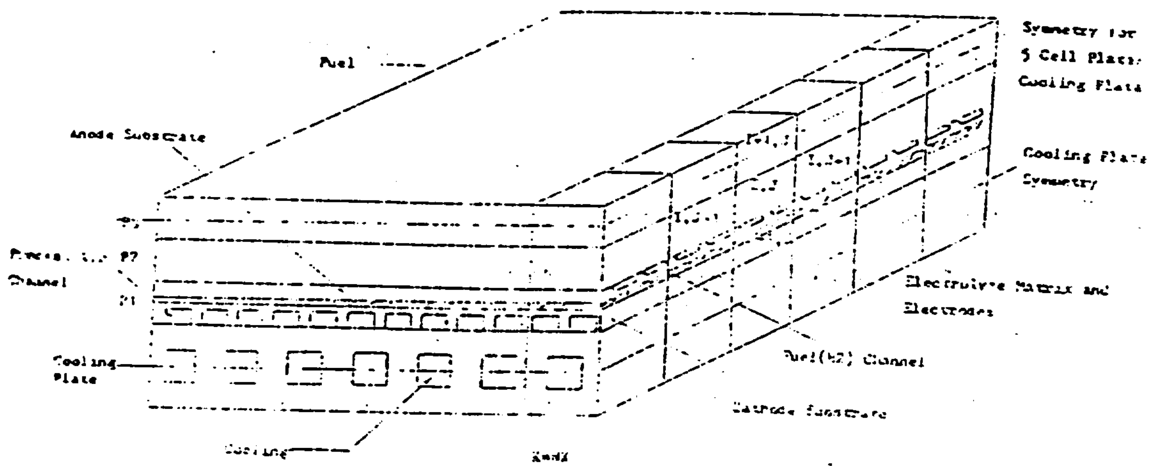



Figure 108. Geometry of the Theoretical Analysis Model.

(f) Temperature gradient in the z-direction is negligibly small.

(g) A adiabatic (isothermal and reversable) behavior is assumed of the fuel cell edges, no correction factor will be used to modify the heat transfer coefficients for the cell and cooling plates.

(h) The transient experimental expression for the cooling fluid convection heat transfer coefficient will be used.

For the chemical reaction inside the fuel cell, the following was assumed:

(a) Fuel to process air operational ratios remains constant throughout the considered testing time intervals.

(b) Phorphoric acid concentration does not change during the considered time intervals.

(c) No significant accumulation in reaction components.

The governing equation can be written as follows for a transient for the considered PAFC components:

Fuel Cell Plate:

The governing equation for the fuel cell plate should include the conduction heat transfer in the x-direction, considering the effect of the thermal contact resistance on the conduction heat transfer in the y-direction, the heat

loss to the process air by convection, the internal heat generation and the effect on the internal energy of the fuel cell plate as follows:

$$K_x \frac{\partial T}{\partial x}\Big|_{x+L_1} - K_x \frac{\partial T}{\partial x}\Big|_x + L_1 K_y \frac{\partial^2 T}{\partial y^2}\Big|_y$$

$$- \frac{c_1 \dot{m}_1}{M_1} \frac{\partial T_1}{\partial y}\Big|_y + I \left(\frac{\Delta H}{F} - V\right) = \rho_1 c_1 L_1 \left(\frac{\partial T}{\partial t}\right) \qquad (35)$$

<u>Cooling Plate</u>:

The governing equation for the fuel cell plate should include the heat conduction in the x-direction, the heat conduction in the y-direction, heat loss to the cooling fluid by convection and the effect of the internal energy of the cooling plate; as follows

$$\left[ 2K_x \frac{\partial T}{\partial x}\Big|_{x+\frac{L_2}{2}} \right] + L_2 K_y \frac{\partial^2 T}{\partial y^2}\Big|_y - \frac{c_2 \dot{m}_2}{M_2} =$$

$$\rho_2 c_2 L_2 \left(\frac{\partial T}{\partial t}\right) \qquad (36)$$

Process Air:

The governing equation for the process air is composed of the heat gain by the process air by convection, the change of the air enthalpy, and the effect of the air enternal energy as follows:

$$h_1 P_1 (T - T_{\infty 1}) - \dot{m}_1 \; c_{p1} \frac{\partial T_1}{\partial t} = \rho_a \; A_1 \; C_1 \frac{\partial T_1}{\partial t} \qquad (37)$$

Cooling Fluid:

The governing equation for the cooling fluid should include the heat transfer to the cooling fluid by convection, the change in the enthalpy of the cooling fluid, and the effect on the internal energy of the cooling fluid, as follows:

$$h_2 P_2 (T - T_2) - \dot{m}_2 \; C_{p2} \frac{\partial T_2}{\partial y} = \rho_f \; A_2 \frac{\partial T_2}{\partial t} \qquad (38)$$

The initial and boundary condition can be minimized as follows:

**(A) START-UP PROCESS**

Start-Up Initial Conditions:

Room temperature at (t=0) = T(x,y,t) = T(x,y,0)

Transient Boundary Conditions:

Geometrical Symmetry (1) $\frac{\partial T}{\partial x} = 0$ at x=0, t>0

Adiabatic Process (2) $\frac{\partial T}{\partial y} = 0$ at y=0, t>0

Geometrical Symmetry (3) $\frac{\partial T}{\partial x} = 0$ at $x = L_x$, t>0

Adiabatic Process (4) $\frac{\partial T}{\partial y} = 0$ at $y = L_y$, t>0

Negligible Temperature Changes in the Z-Direction $\frac{\partial T}{\partial z} = 0$ at $0<z\leq L_z$, t>0

Process air inlet temperature (6) $T_1(x,0,t) = \overset{*}{C}_1$ $t>0$

Coolant fluid inlet temperature (7) $T_2(x,0,t) = \overset{*}{C}_2$ $t>0$

except in the case of oil coolant): $T_2(x,0,t) = \overset{*}{C}_3$ $t>0$

where $\overset{*}{C}_3 = \overset{*}{C}_2 + \eta$

Note: For water coolant $h_2(t) = 31.088\ (Re^{0.05779})(e^{0.00953t})$
$(Pr^{0.01433})(e^{0.0001240}) - 31.088$
$(Re^{0.05779})(Pr^{0.01433})(e^{0.0001240})$

For oil coolant $h_2(t) = 16.088\ (Re^{0.216})(e^{0.00961t})$
$(Pr^{0.0076})(e^{1.356*10\text{-}40}) - 16.088$
$(Re^{0.216})(Pr^{0.0076})(e^{1.356*10\text{-}40})$

**(B) SHUT-DOWN PROCESS**

The initial and boundary conditions can be summarized as follows for the shut-down process that will start from a steady state operation condition when t=120 minutes:

<u>Shut-Down Initial Conditions</u>:

Average cell temperature at (t=120 minutes) = $t(x,y,t) = T(x,y,120)$

<u>Transient Boundary Condition</u>:

Geometrical symmetry (1) $\frac{\partial T}{\partial x} = 0$ at $x=0$, $t>120$

Adiabatic process (2) $\frac{\partial T}{\partial y} = 0$ at $y=0$, $t>120$

Geometrical symmetry (3) $\frac{\partial T}{\partial y} = 0$ at $y=L_x$, $t>120$

Adiabatic process (4) $\frac{\partial T}{\partial y} = 0$ at $y=L_y$, $t>120$

Negligible temperature $\frac{\partial T}{\partial z} = 0$ at $z \le L_z$, $t > 120$

change in the z-direction (5)

Process air inlet temperature (6) $T_1(x,0,t) = \overset{*}{C}_1$ $t > 120$ min

Coolant fluid inlet temperature (7) $T_2(x,0,t) = \overset{*}{C}_2$ $t > 120$ min

(except in oil case): $T_2(x,0,t) = \overset{*}{C}_3$ $t > 120$ min

Note: For water coolant: $h_s(t) = 70.088 * (Re^{0.05779}) * (Pr^{0.01433}) *$

$[\exp(-0.00891t + 0.000123\ o)$

For oil coolant: $h_s(t) = 35.044 * (Re^{0.21506}) *$

$(Pr^{7.614*10^{-3}})\ [\exp(-0.00901t +$

$1.356*10^{-4}\ o)$

where

$T = T(x,y,t)$ = Temperature converted to ($C^o$)

$T_1$ = fuel cell plate temperature ($C^o$)

$T_2$ = cooling plate temperature ($C^o$)

$K_x$ = effective thermal conductivity in stacking

direction in $(\frac{W}{m\text{-}C})$

$K_y$ = effective thermal conductivity in the process air

direction in $(\frac{W}{m\ C^o})$

$\dot{m}_1$ = process air mass flow rate (Kg/hr)

$\dot{m}_2$ = cooling fluid mass flow rate (Kg/hr)

$L_1$ = fuel cell plate thickness (m)

$L_2$ = cooling plate thickness (m)

$L_x$ = high of the considered slice (m)

$L_y$ = length of the considered slice (m)

$\Delta H$ = molar heat of reaction of hydrogen

$F$ = Faraday's constant, (constant/meter)

$V$ = voltage (volts)

$I$ = Current density $(\frac{Amps}{m^2})$

$c_{p1}$ = fuel cell plate specific heat $(\frac{J}{K_g-C^o})$

$c_{p2}$ = cooling plate specific heat $\frac{J}{KgC^o})$

$M_1$ = fuel cell plate pitch (m)

$M_2$ = cooling plate pitch (m)

$\rho_1$ = fuel cell plate density ($Kg/m^3$)

$\rho_2$ = cooling plate density ($Kg/m^3$)

$\rho_a$ = molar density of air ($gm\text{-}mk/m^3$)

$P_1$ = process air channel perimeter (m)

$P_2$ = cooling tube perimeter (m)

$A_1$ = process air channel cross-section area ($m^2$)

$A_2$ = cooling air channel cross-section area ($m^2$)

$h_1$ = convection heat transfer inside process air channel $\frac{W}{m^2\ C^o})$

$h_2$ = convection heat transfer coefficient inside cooling tubes $(\frac{W}{m^2\ C^o})$

<u>Note</u>: The purpose for using ($^*C_3$) in the case of oil, is to account for the higher temperature of the cooling fluid due to the effectiveness of the cooling heat exchange of the secondary cooling system.

The partial differential equations were solved by the

finite difference method utilizing the available initial and boundary conditions. The developed Fortran computer code was then used to generate the theoretical temperature profiles, the average temperature, the current density profiles and the average current density for the start-up and shut-down process under different operations conditions and for the two incompressible fluids.

The importance and the accuracy of the data generated by the electrode depends on the consideration of the design and operation parameters, the cooling system configuration, cooling fluid properties and current density effects on the electrode temperature distribution.

In addition, two of the parameters that affect the performance of the cooling system predicted by the computer code are the plates dimensions and the fuel cell stack material construction and design. The consideration of those two parameters will make the code sensitive to the material properties of the cooling and cell plates, such as the thermal conductivity, the cooling system and the sandwiched cell plates configurations, and the properties of the working fluid.

In the theoretical analysis considered above, the computer code was modified in order to predict the performance of a fuel cell that was simulated by the experimental model by considering the following design parameters:

(a) Cooling and fuel cell plates dimensions.

(b) Cooling and fuel cell plate thermal conductivities.

(c) Mass flow rate of cooling incompressible fluids utilized.

(d) Serpentine cooling system dimensions and configurations.

(e) Thermophysical properties of the utilized cooling fluids.

(f) Inlet temperature of the cooling fluid (oil coolant only.

(g) Total applied stack pressure.

(h) The sequence of the monitoring time intervals.

The output data file modified to demonstrate the transient electrode temperature distribution. The initial conditions will determine whether the performed test is a start-up or a shut-down process.

## 5.4 Analytical Results

In this section the results generated by the theoretical analysis will be presented and appropriate analysis will be made to provide the needed information for a comparison betweeen the experimental and theoretical results.

### 5.4.1 Start-Up Process

The transient temperature profiles for a start-up process are demonstrated by Table I to Table IV, only for maximum and minimum applied stack pressure, with minimum, average, and maximum mass flow rates, when water is employed as a coolant. Figure 109 summarizes the variation in the average electrode temperature during the different considered start-up processes. As noticed in the experimental results, there is a tendency toward a higher average electrode temperature with higher applied stack pressure on the average of nearly $2.075 * 10^{-3}$ °C per additional KPa. On the other hand, the average electrode temperature will drop with higher coolant mass flow rate or Re numbers. In addition, the transient temperature differential seems to decrease remarkably between the isotherms with higher stack pressure, but the opposite is noticed with the same stack pressure but lower mass flow rates.

Similar results were observed when oil was used as the cooling fluid as exhibited by sample Table C-I and Table-II

in the appendix, which show maximum and minimum applied stack pressure for the minimum, maximum, and average Re numbers, the change of the electrode temperature distribution during a start-up. The temperature distribution gradually becomes more uniform with higher applied stack pressure. Figure 110 shows the variation of the average temperature for the considered as a function of time and also a dependent of the applied stack pressure approximately $1.109 * 10^{-3}$ °C/KPa.

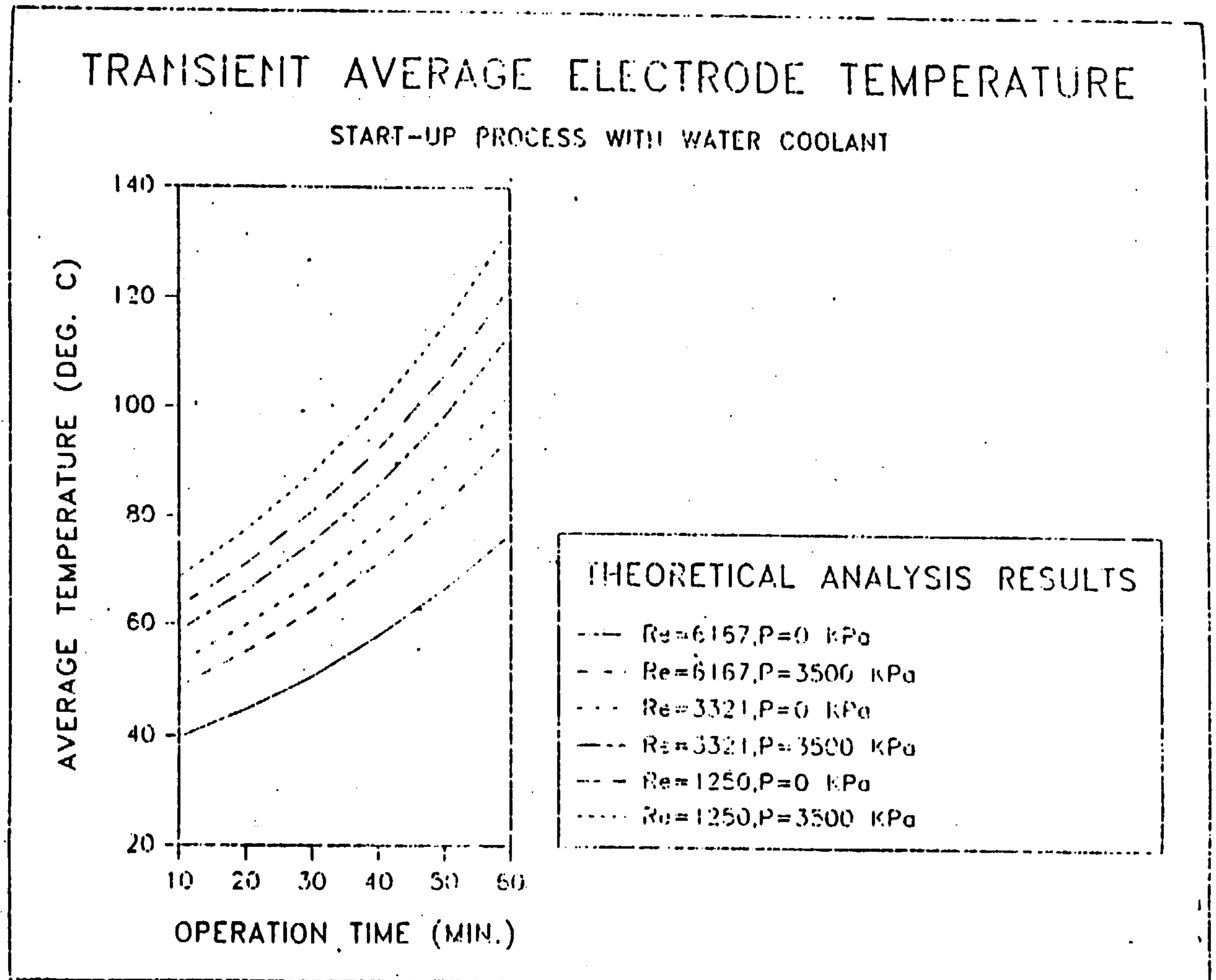



Figure 109. Theoretical Transient Average Electrode Temperature During Start-Ups with Water Coolant.

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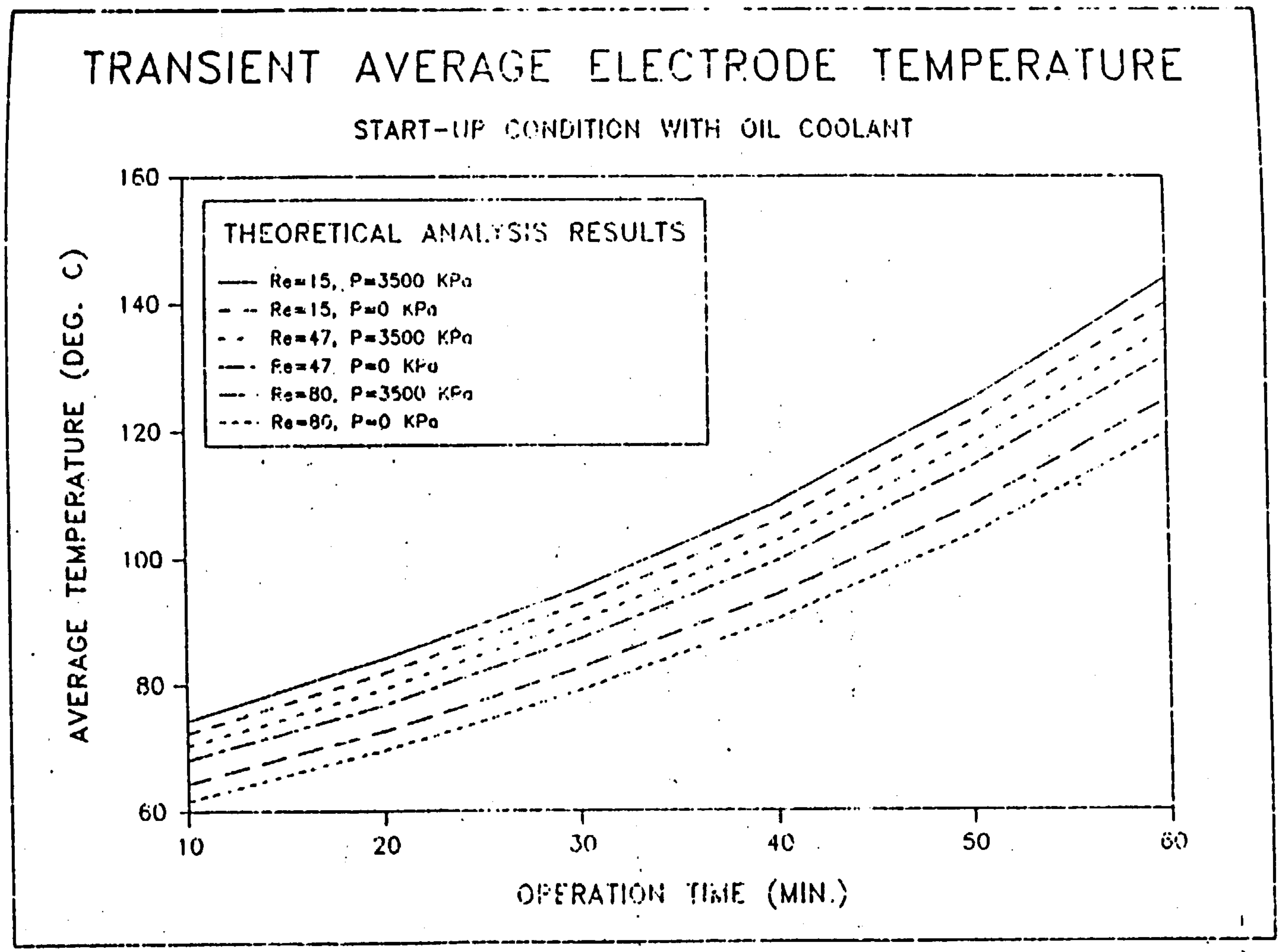


Figure 110. Theoretical Transient Average Electrode Temperature During Start-Ups with Oil Coolant.

Table I. Start-Up Process with Water Coolant
(P=3500 KPa, Re=1250)

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 66.631
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 83.162 | 82.404 | 81.645 | 80.886 | 80.128 | 79.369 | 78.611 | 77.852 | 77.094 |
| 81.509 | 80.748 | 79 938 | 79.228 | 78.467 | 77.707 | 76.946 | 76.186 | 75.426 |
| 79.719 | 78.958 | 78.197 | 77.436 | 76.675 | 75.914 | 75.153 | 74.392 | 73.631 |
| 78.009 | 77.246 | 76.484 | 75.722 | 74.959 | 74.197 | 73.434 | 72.672 | 71.910 |
| 76.252 | 75.489 | 74.725 | 73.962 | 73.199 | 72.435 | 71.672 | 70.908 | 70.145 |
| 74.589 | 73.824 | 73.058 | 72.293 | 71.527 | 70.762 | 69.996 | 69.231 | 68.466 |
| 72.734 | 71.969 | 71.203 | 70.438 | 69.672 | 68.907 | 68.141 | 67.376 | 66.610 |
| 70.140 | 69.382 | 68.625 | 67.867 | 67.109 | 66.352 | 65.594 | 64.836 | 64.079 |
| 68.257 | 67.499 | 66.742 | 65.985 | 65.228 | 64.470 | 63.713 | 62.956 | 62.199 |
| 66.346 | 65.589 | 64.833 | 64.076 | 63.320 | 62.563 | 61.807 | 61.050 | 60.294 |
| 63.467 | 62.722 | 61.978 | 61.233 | 60.489 | 59.745 | 59.000 | 58.256 | 57.512 |
| 59.268 | 58.552 | 57.837 | 57 121 | 56.405 | 55.690 | 54.974 | 54.259 | 53.543 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 77.372
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 94.006 | 93.148 | 92.291 | 91.433 | 90.576 | 89.718 | 88.861 | 88.003 | 87.146 |
| 92.341 | 91.480 | 90.618 | 89.757 | 88.895 | 88.034 | 87.172 | 86.311 | 85.450 |
| 90.384 | 89.521 | 88.658 | 87.795 | 86.932 | 86.070 | 85.207 | 84.344 | 83.481 |
| 88.601 | 87.735 | 86.869 | 86.003 | 85.137 | 84.271 | 83.406 | 82.540 | 81.674 |
| 86.713 | 85.844 | 84.976 | 84.108 | 83.240 | 82.372 | 81.504 | 80.636 | 79.768 |
| 85.038 | 84.165 | 83.292 | 82.420 | 81.547 | 80.675 | 79.802 | 78.929 | 78.057 |
| 82.969 | 82.096 | 81.222 | 80.349 | 79.476 | 78.603 | 77.729 | 76.856 | 75.983 |
| 79.187 | 78.331 | 77.476 | 76.620 | 75.765 | 74.910 | 74.054 | 73.199 | 72.343 |

Table I (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 76.165 | 75.310 | 74.456 | 73.601 | 72.747 | 71.892 | 71.038 | 70.183 |
| [illegible] | 73.936 | 73.083 | 72.231 | 71.378 | 70.525 | 69.672 | 68.819 | 67.967 |
| [illegible] | 69.563 | 68.738 | 67.912 | 67.087 | 66.261 | 65.436 | 64.610 | 63.784 |
| [illegible] | 62.432 | 61.669 | 60.906 | 60.143 | 59.380 | 58.617 | 57.854 | 57.091 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 30.00
ENDING TIME = 40.00
AVERAGE TEMPERATURE = 87.744
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 106.888 | 105.913 | 104.938 | 103.963 | 102.989 | 102.014 | 101.039 | 100.064 | 99.089 |
| 105.209 | 104.227 | 103.246 | 102.264 | 101.283 | 100.301 | 99.320 | 98.338 | 97.357 |
| 103.057 | 102.074 | 101.090 | 100.106 | 99.122 | 98.139 | 97.155 | 96.171 | 95.187 |
| 101.194 | 100.205 | 99.216 | 98.227 | 97.238 | 96.249 | 95.260 | 94.271 | 93.282 |
| 99.150 | 98.157 | 97.164 | 96.172 | 95.179 | 94.186 | 93.194 | 92.201 | 91.208 |
| 97.474 | 96.473 | 95.473 | 94.473 | 93.473 | 92.472 | 91.472 | 90.472 | 89.471 |
| 95.192 | 94.190 | 93.189 | 92.187 | 91.185 | 90.183 | 89.181 | 88.179 | 87.177 |
| [illegible] | 88.947 | 87.976 | 87.005 | 86.033 | 85.062 | 84.091 | 83.119 | 82.148 |
| 87.410 | 86.440 | 85.471 | 84.501 | 83.531 | 82.562 | 81.592 | 80.622 | 79.652 |
| 84.795 | 83.829 | 82.862 | 81.895 | 80.928 | 79.961 | 78.994 | 78.027 | 77.060 |
| 78.513 | 77.592 | 76.671 | 75.750 | 74.829 | 73.908 | 72.988 | 72.067 | 71.146 |
| 67.773 | 66.954 | 66.136 | 65.318 | 64.499 | 63.681 | 62.863 | 62.045 | 61.226 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 40.00
ENDING TIME = 50.00
AVERAGE TEMPERATURE =100.100
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 22.251 | 121.136 | 120.021 | 118.906 | 117.791 | 116.676 | 115.561 | 114.446 | 113.331 |
| 20.552 | 119.428 | 118.303 | 117.179 | 116.054 | 114.929 | 113.805 | 112.680 | 111.556 |
| 18.177 | 117.049 | 115.920 | 114.792 | 113.664 | 112.536 | 111.408 | 110.280 | 109.152 |
| 15.224 | 115.088 | 113.952 | 112.817 | 111.681 | 110.545 | 109.409 | 108.273 | 107.137 |

Table I (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 113.993 | 112.852 | 111.711 | 110.569 | 109.428 | 108.287 | 107.146 | 106.004 | 104.863 |
| 112.331 | 111.178 | 110.025 | 108.873 | 107.720 | 106.567 | 105.415 | 104.262 | 103.109 |
| 109.850 | 108.694 | 107.538 | 106.381 | 105.225 | 104.069 | 102.913 | 101.757 | 100.600 |
| 102.597 | 101.588 | 100.478 | 99.369 | 98.260 | 97.150 | 96.041 | 94.932 | 93.822 |
| 99.779 | 98.672 | 97.565 | 96.458 | 95.351 | 94.244 | 93.137 | 92.030 | 90.923 |
| 96.698 | 95.596 | 94.493 | 93.391 | 92.288 | 91.185 | 90.083 | 88.980 | 87.878 |
| 88.074 | 87.041 | 86.008 | 84.976 | 83.943 | 82.910 | 81.877 | 80.844 | 79.811 |
| 73.103 | 72.221 | 71.338 | 70.456 | 69.573 | 68.690 | 67.808 | 66.925 | 66.043 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 50.00
ENDING TIME = 60.00
AVERAGE TEMPERATURE =114.872
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 140.645 | 139.362 | 138.079 | 136.796 | 135.514 | 134.231 | 132.948 | 131.665 | 130.382 |
| 138.921 | 137.625 | 136.329 | 135.033 | 133.737 | 132.441 | 131.145 | 129.849 | 128.553 |
| 136.284 | 134.983 | 133.682 | 132.381 | 131.080 | 129.779 | 128.478 | 127.177 | 125.877 |
| 134.233 | 132.921 | 131.609 | 130.297 | 128.986 | 127.674 | 126.362 | 125.050 | 123.738 |
| 131.779 | 130.460 | 129.140 | 127.821 | 126.502 | 125.182 | 123.863 | 122.544 | 121.224 |
| 130.151 | 128.816 | 127.480 | 126.145 | 124.809 | 123.473 | 122.138 | 120.802 | 119.467 |
| 127.500 | 126.158 | 124.816 | 123.474 | 122.132 | 120.790 | 119.448 | 118.106 | 116.764 |
| 117.972 | 116.697 | 115.423 | 114.148 | 112.874 | 111.600 | 110.325 | 109.051 | 107.777 |
| 114.557 | 113.206 | 112.016 | 110.745 | 109.474 | 108.203 | 106.932 | 105.661 | 104.390 |
| 110.912 | 109.647 | 108.382 | 107.118 | 105.853 | 104.588 | 103.323 | 102.059 | 100.794 |
| 99.366 | 98.200 | 97.035 | 95.869 | 94.704 | 93.539 | 92.373 | 91.208 | 90.042 |
| 79.311 | 78.353 | 77.396 | 76.438 | 75.481 | 74.523 | 73.566 | 72.608 | 71.650 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 60.00
ENDING TIME = 70.00
AVERAGE TEMPERATURE =132.605
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

Table I. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| …2.758 | 161.273 | 159.789 | 158.304 | 156.820 | 155.335 | 153.850 | 152.366 | 150.881 |
| …0.999 | 159.497 | 157.995 | 156.494 | 154.992 | 153.490 | 151.988 | 150.486 | 148.984 |
| …8.059 | 156.551 | 155.042 | 153.533 | 152.024 | 150.515 | 149.007 | 147.498 | 145.989 |
| …5.900 | 154.376 | 152.852 | 151.329 | 149.805 | 148.281 | 146.758 | 145.234 | 143.711 |
| …53.177 | 151.643 | 150.110 | 148.576 | 147.042 | 145.509 | 143.975 | 142.442 | 140.908 |
| …51.613 | 150.057 | 148.501 | 146.945 | 145.390 | 143.834 | 142.278 | 140.722 | 139.166 |
| …48.843 | 147.277 | 145.710 | 144.143 | 142.577 | 141.010 | 139.444 | 137.877 | 136.310 |
| …36.304 | 134.831 | 133.359 | 131.887 | 130.414 | 128.942 | 127.469 | 125.997 | 124.525 |
| …32.288 | 130.820 | 129.353 | 127.885 | 126.417 | 124.950 | 123.482 | 122.014 | 120.547 |
| …27.952 | 126.493 | 125.034 | 123.575 | 122.116 | 120.657 | 119.198 | 117.739 | 116.280 |
| …12.745 | 111.423 | 110.100 | 108.778 | 107.456 | 106.133 | 104.811 | 103.489 | 102.166 |
| 86.544 | 85.500 | 84.455 | 83.410 | 82.365 | 81.320 | 80.275 | 79.230 | 78.185 |

Table II. Start-Up Process with Water Coolant (P=0 KPa, Re=1250).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 63.163
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 77.543 | 76.818 | 76.094 | 75.369 | 74.644 | 73.919 | 73.194 | 72.469 | 71.744 |
| 75.865 | 75.140 | 74.413 | 73.686 | 72.960 | 72.233 | 71.507 | 70.780 | 70.054 |
| 74.062 | 73.334 | 72.607 | 71.880 | 71.153 | 70.426 | 69.699 | 68.971 | 68.244 |
| 72.321 | 71.602 | 70.874 | 70.145 | 69.417 | 68.688 | 67.960 | 67.231 | 66.503 |
| 70.557 | 69.827 | 69.098 | 68.368 | 67.639 | 66.909 | 66.180 | 65.450 | 64.721 |
| 68.868 | 68.137 | 67.405 | 66.674 | 65.942 | 65.211 | 64.480 | 63.748 | 63.017 |
| 67.002 | 66.271 | 65.539 | 64.808 | 64.076 | 63.345 | 62.613 | 61.882 | 61.150 |
| 64.457 | 63.733 | 63.009 | 62.285 | 61.561 | 60.837 | 60.113 | 59.389 | 58.665 |
| 62.567 | 61.843 | 61.119 | 60.396 | 59.672 | 58.949 | 58.225 | 57.501 | 56.778 |
| 60.651 | 59.928 | 59.205 | 58.482 | 57.760 | 57.037 | 56.314 | 55.591 | 54.868 |
| 57.853 | 57.142 | 56.431 | 55.720 | 55.008 | 54.297 | 53.586 | 52.874 | 52.163 |
| 53.862 | 53.178 | 52.495 | 51.811 | 51.127 | 50.443 | 49.760 | 49.076 | 48.392 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 71.214
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 87.654 | 86.835 | 86.015 | 85.196 | 84.377 | 83.557 | 82.738 | 81.919 | 81.099 |
| 85.949 | 85.125 | 84.302 | 83.479 | 82.656 | 81.833 | 81.010 | 80.187 | 79.363 |
| 83.970 | 83.145 | 82.321 | 81.496 | 80.672 | 79.847 | 79.023 | 78.199 | 77.375 |
| 82.152 | 81.325 | 80.497 | 79.670 | 78.843 | 78.015 | 77.188 | 76.360 | 75.533 |
| 80.236 | 79.406 | 78.577 | 77.747 | 76.917 | 76.088 | 75.258 | 74.429 | 73.599 |
| 78.516 | 77.682 | 76.848 | 76.014 | 75.180 | 74.346 | 73.512 | 72.678 | 71.845 |
| 76.430 | 75.596 | 74.761 | 73.927 | 73.093 | 72.258 | 71.424 | 70.589 | 69.755 |
| 72.770 | 71.953 | 71.136 | 70.318 | 69.501 | 68.684 | 67.866 | 67.049 | 66.231 |

Table II. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 70.599 | 69.782 | 68.965 | 68.149 | 67.332 | 66.516 | 65.699 | 64.883 | 64.066 |
| 68.370 | 67.555 | 66.740 | 65.925 | 65.110 | 64.295 | 63.480 | 62.665 | 61.851 |
| 64.164 | 63.375 | 62.586 | 61.797 | 61.008 | 60.219 | 59.430 | 58.642 | 57.853 |
| 57.431 | 56.702 | 55.973 | 55.244 | 54.515 | 53.786 | 53.056 | 52.327 | 51.598 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 30.00
ENDING TIME = 40.00
AVERAGE TEMPERATURE = 80.768
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 99.666 | 98.735 | 97.803 | 96.872 | 95.940 | 95.008 | 94.077 | 93.145 | 92.213 |
| 97.926 | 96.988 | 96.050 | 95.112 | 94.174 | 93.236 | 92.298 | 91.361 | 90.423 |
| 95.744 | 94.804 | 93.864 | 92.924 | 91.984 | 91.044 | 90.104 | 89.164 | 88.224 |
| 93.829 | 92.884 | 91.939 | 90.994 | 90.049 | 89.104 | 88.159 | 87.214 | 86.269 |
| 91.744 | 90.795 | 89.847 | 88.898 | 87.950 | 87.001 | 86.053 | 85.104 | 84.156 |
| 89.998 | 89.042 | 88.086 | 87.130 | 86.174 | 85.218 | 84.263 | 83.307 | 82.351 |
| 87.691 | 86.733 | 85.776 | 84.818 | 83.861 | 82.904 | 81.946 | 80.989 | 80.032 |
| 82.633 | 81.705 | 80.777 | 79.849 | 78.920 | 77.992 | 77.064 | 76.136 | 75.206 |
| 80.123 | 79.197 | 78.270 | 77.343 | 76.417 | 75.490 | 74.563 | 73.637 | 72.710 |
| 77.517 | 76.593 | 75.669 | 74.746 | 73.822 | 72.898 | 71.974 | 71.050 | 70.126 |
| 71.569 | 70.689 | 69.809 | 68.929 | 68.049 | 67.169 | 66.289 | 65.409 | 64.530 |
| 61.591 | 60.809 | 60.028 | 59.246 | 58.464 | 57.682 | 56.900 | 56.118 | 55.336 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 40.00
ENDING TIME = 50.00
AVERAGE TEMPERATURE = 92.149
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 113.991 | 112.926 | 111.860 | 110.795 | 109.729 | 108.664 | 107.598 | 106.533 | 105.467 |
| 112.207 | 111.132 | 110.058 | 108.983 | 107.909 | 106.834 | 105.759 | 104.685 | 103.610 |
| 109.790 | 108.712 | 107.634 | 106.556 | 105.479 | 104.401 | 103.323 | 102.245 | 101.167 |
| 107.765 | 106.680 | 105.594 | 104.509 | 103.423 | 102.338 | 101.253 | 100.167 | 99.082 |

Table II. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 105.479 | 104.388 | 103.296 | 102.207 | 101.115 | 100.026 | 98.935 | 97.845 | 96.754 |
| 103.715 | 102.614 | 101.512 | 100.411 | 99.309 | 98.208 | 97.106 | 96.005 | 94.903 |
| 101.193 | 100.088 | 98.983 | 97.879 | 96.774 | 95.669 | 94.564 | 93.459 | 92.355 |
| 94.376 | 93.316 | 92.256 | 91.196 | 90.136 | 89.076 | 88.016 | 86.956 | 85.895 |
| 91.461 | 90.403 | 89.345 | 88.287 | 87.229 | 86.172 | 85.114 | 84.056 | 82.998 |
| 88.399 | 87.345 | 86.291 | 85.238 | 84.184 | 83.131 | 82.077 | 81.023 | 79.970 |
| 80.285 | 79.298 | 78.311 | 77.324 | 76.337 | 75.350 | 74.363 | 73.375 | 72.388 |
| 66.436 | 65.593 | 64.749 | 63.906 | 63.062 | 62.219 | 61.376 | 60.532 | 59.689 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 50.00
ENDING TIME = 60.00
AVERAGE TEMPERATURE =105.756
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 131.142 | 129.916 | 128.691 | 127.465 | 126.239 | 125.013 | 123.787 | 122.561 | 121.335 |
| 129.304 | 128.065 | 126.827 | 125.589 | 124.350 | 123.112 | 121.873 | 120.635 | 119.397 |
| 126.613 | 125.370 | 124.127 | 122.883 | 121.640 | 120.397 | 119.154 | 117.911 | 116.668 |
| 124.463 | 123.209 | 121.956 | 120.702 | 119.449 | 118.195 | 116.942 | 115.688 | 114.434 |
| 121.936 | 120.675 | 119.415 | 118.154 | 116.893 | 115.633 | 114.372 | 113.111 | 111.850 |
| 120.169 | 118.893 | 117.617 | 116.340 | 115.064 | 113.788 | 112.512 | 111.235 | 109.959 |
| 117.452 | 116.170 | 114.887 | 113.605 | 112.323 | 111.040 | 109.758 | 108.476 | 107.193 |
| 108.413 | 107.195 | 105.977 | 104.760 | 103.542 | 102.324 | 101.107 | 99.889 | 98.671 |
| 105.007 | 103.793 | 102.579 | 101.364 | 100.150 | 98.935 | 97.721 | 96.506 | 95.292 |
| 101.392 | 100.183 | 98.975 | 97.766 | 96.558 | 95.349 | 94.141 | 92.932 | 91.724 |
| 90.578 | 89.464 | 88.350 | 87.237 | 86.123 | 85.009 | 83.896 | 82.782 | 81.669 |
| 72.077 | 71.162 | 70.247 | 69.332 | 68.417 | 67.502 | 66.587 | 65.672 | 64.757 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 60.00
ENDING TIME = 70.00
AVERAGE TEMPERATURE =122.091
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

Table II. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 150.342 | 148.924 | 147.505 | 146.087 | 144.668 | 143.250 | 141.831 | 140.412 |
| 149.854 | 148.419 | 146.984 | 145.548 | 144.113 | 142.678 | 141.243 | 139.808 | 138.373 |
| 146.843 | 145.401 | 143.959 | 142.518 | 141.076 | 139.634 | 138.192 | 136.751 | 135.309 |
| 144.553 | 143.097 | 141.641 | 140.185 | 138.729 | 137.273 | 135.817 | 134.361 | 132.905 |
| 141.735 | 140.270 | 138.804 | 137.339 | 135.874 | 134.408 | 132.943 | 131.478 | 130.012 |
| 139.984 | 138.498 | 137.011 | 135.524 | 134.038 | 132.551 | 131.064 | 129.578 | 128.091 |
| 137.113 | 135.616 | 134.119 | 132.622 | 131.126 | 129.629 | 128.132 | 126.635 | 125.138 |
| 125.260 | 123.853 | 122.446 | 121.039 | 119.632 | 118.225 | 116.818 | 115.411 | 114.004 |
| 121.260 | 119.857 | 118.455 | 117.053 | 115.650 | 114.248 | 112.845 | 111.443 | 110.041 |
| 116.969 | 115.575 | 114.181 | 112.787 | 111.393 | 109.998 | 108.604 | 107.210 | 105.816 |
| 102.774 | 101.510 | 100.247 | 98.983 | 97.719 | 96.456 | 95.192 | 93.929 | 92.665 |
| 78.651 | 77.653 | 76.654 | 75.656 | 74.657 | 73.659 | 72.660 | 71.662 | 70.663 |

Table III. Start-Up Process with Water Coolant (P=3500 KPa, Re=3321).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 58.739
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 71.924 | 71.166 | 70.407 | 69.649 | 68.890 | 68.132 | 67.373 | 66.614 | 65.856 |
| 70.484 | 69.724 | 68.963 | 68.203 | 67.442 | 66.682 | 65.922 | 65.161 | 64.401 |
| 68.925 | 68.164 | 67.403 | 66.642 | 65.881 | 65.120 | 64.359 | 63.598 | 62.837 |
| 67.436 | 66.673 | 65.911 | 65.149 | 64.386 | 63.624 | 62.861 | 62.099 | 61.337 |
| 65.906 | 65.143 | 64.379 | 63.616 | 62.852 | 62.089 | 61.326 | 60.562 | 59.799 |
| 64.457 | 63.692 | 62.926 | 62.161 | 61.395 | 60.630 | 59.8[illegible] | 59.099 | 58.334 |
| 62.842 | 62.077 | 61.311 | 60.546 | 59.780 | 59.015 | 58.249 | 57.484 | 56.718 |
| 60.589 | 59.831 | 59.073 | 58.316 | 57.558 | 56.800 | 56.043 | 55.285 | 54.5[illegible] |
| 58.950 | 58.192 | 57.435 | 56.678 | 55.921 | 55.163 | 54.406 | 53.649 | 52.892 |
| 57.287 | 56.530 | 55.774 | 55.017 | 54.261 | 53.504 | 52.748 | 51.991 | 51.235 |
| 54.788 | 54.043 | 53.299 | 52.555 | 51.810 | 51.066 | 50.322 | 49.577 | 48.833 |
| 51.150 | 50.435 | 49.719 | 49.004 | 48.288 | 47.573 | 46.857 | 46.142 | 45.426 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 66.220
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 81.303 | 80.445 | 79.588 | 78.730 | 77.873 | 77.015 | 76.158 | 75.300 | 74.443 |
| 79.851 | 78.990 | 78.128 | 77.267 | 76.405 | 75.544 | 74.682 | 73.821 | 72.960 |
| 78.146 | 77.283 | 76.421 | 75.558 | 74.695 | 73.832 | 72.969 | 72.107 | 71.244 |
| 76.592 | 75.727 | 74.861 | 73.995 | 73.129 | 72.263 | 71.397 | 70.531 | 69.665 |
| 74.947 | 74.079 | 73.211 | 72.343 | 71.475 | 70.607 | 69.738 | 68.870 | 68.00[illegible] |
| 73.486 | 72.614 | 71.741 | 70.868 | 69.996 | 69.123 | 68.251 | 67.378 | 66.505 |
| 71.685 | 70.812 | 69.939 | 69.065 | 68.192 | 67.319 | 66.445 | 65.572 | 64.699 |
| 58.404 | 67.548 | 66.693 | 65.837 | 64.982 | 64.127 | 63.271 | 62.416 | 61.56[illegible] |

Table III. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 65.663 | 64.309 | 63.954 | 63.099 | 62.245 | 61.390 | 60.536 | 59.681 |
| [illegible] | 63.724 | 62.871 | 62.019 | 61.166 | 60.313 | 59.460 | 58.607 | 57.755 |
| 60.764 | 59.938 | 59.112 | 58.287 | 57.461 | 56.636 | 55.810 | 54.985 | 54.159 |
| 54.540 | 53.777 | 53.014 | 52.251 | 51.488 | 50.725 | 49.962 | 49.199 | 48.436 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 30.00
ENDING TIME = 40.00
AVERAGE TEMPERATURE = 75.039
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 92.444 | 91.469 | 90.494 | 89.520 | 88.545 | 87.570 | 86.595 | 85.620 | 84.645 |
| 90.978 | 89.997 | 89.015 | 88.034 | 87.052 | 86.071 | 85.089 | 84.108 | 83.126 |
| 89.104 | 88.120 | 87.137 | 86.153 | 85.169 | 84.185 | 83.202 | 82.218 | 81.234 |
| 87.479 | 86.490 | 85.501 | 84.512 | 83.523 | 82.534 | 81.545 | 80.556 | 79.567 |
| 85.697 | 84.704 | 83.711 | 82.719 | 81.726 | 80.733 | 79.741 | 78.748 | 77.756 |
| 84.233 | 83.233 | 82.232 | 81.232 | 80.232 | 79.232 | 78.231 | 77.231 | 76.231 |
| 82.246 | 81.244 | 80.242 | 79.240 | 78.238 | 77.237 | 76.235 | 75.233 | 74.231 |
| 77.674 | 76.703 | 75.731 | 74.760 | 73.789 | 72.817 | 71.846 | 70.875 | 69.903 |
| 75.491 | 74.522 | 73.552 | 72.582 | 71.612 | 70.643 | 69.673 | 68.703 | 67.733 |
| 73.217 | 72.250 | 71.283 | 70.316 | 69.350 | 68.383 | 67.416 | 66.449 | 65.482 |
| 67.776 | 66.855 | 65.935 | 65.014 | 64.093 | 63.172 | 62.251 | 61.330 | 60.410 |
| 58.490 | 57.672 | 56.854 | 56.036 | 55.217 | 54.399 | 53.581 | 52.763 | 51.944 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 40.00
ENDING TIME = 50.00
AVERAGE TEMPERATURE = 85.675
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 105.731 | 104.616 | 103.501 | 102.386 | 101.271 | 100.156 | 99.041 | 97.926 | 96.811 |
| 104.246 | 103.122 | 101.997 | 100.873 | 99.748 | 98.623 | 97.499 | 96.374 | 95.250 |
| 102.176 | 101.048 | 99.920 | 98.792 | 97.664 | 96.536 | 95.408 | 94.280 | 93.151 |
| 100.472 | 99.336 | 98.200 | 97.064 | 95.928 | 94.792 | 93.657 | 92.521 | 91.385 |

Table III. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9.526 | 97.385 | 96.244 | 95.103 | 93.961 | 92.820 | 91.679 | 90.538 | 89.396 |
| 7.072 | 95.919 | 94.767 | 93.614 | 92.461 | 91.308 | 90.156 | 89.003 | 87.850 |
| 94.910 | 93.754 | 92.598 | 91.442 | 90.286 | 89.129 | 87.973 | 86.817 | 85.661 |
| 9.712 | 87.603 | 86.494 | 85.384 | 84.275 | 83.166 | 82.056 | 80.947 | 79.838 |
| 6.173 | 85.066 | 83.959 | 82.852 | 81.745 | 80.639 | 79.532 | 78.425 | 77.318 |
| 3.495 | 82.392 | 81.290 | 80.187 | 79.084 | 77.982 | 76.879 | 75.777 | 74.674 |
| 6.031 | 74.998 | 73.965 | 72.932 | 71.899 | 70.866 | 69.833 | 68.800 | 67.767 |
| 63.091 | 62.209 | 61.326 | 60.443 | 59.561 | 58.678 | 57.795 | 56.913 | 56.030 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 50.00
ENDING TIME = 60.00
AVERAGE TEMPERATURE = 98.320
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 21.639 | 120.357 | 119.074 | 117.791 | 116.508 | 115.225 | 113.942 | 112.659 | 111.376 |
| 20.130 | 118.834 | 117.538 | 116.242 | 114.946 | 113.650 | 112.354 | 111.056 | 109.763 |
| 117.832 | 116.531 | 115.230 | 113.929 | 112.628 | 111.327 | 110.026 | 108.725 | 107.425 |
| 16.040 | 114.728 | 113.416 | 112.104 | 110.792 | 109.480 | 108.169 | 106.857 | 105.545 |
| 13.899 | 112.580 | 111.260 | 109.941 | 108.622 | 107.302 | 105.963 | 104.664 | 103.344 |
| 12.472 | 111.136 | 109.801 | 108.465 | 107.130 | 105.794 | 104.458 | 103.123 | 101.787 |
| 10.160 | 108.918 | 107.476 | 106.134 | 104.792 | 103.450 | 102.108 | 100.766 | 99.424 |
| 01.907 | 100.633 | 99.358 | 98.084 | 96.810 | 95.535 | 94.261 | 92.987 | 91.712 |
| 98.937 | 97.666 | 96.395 | 95.124 | 93.853 | 92.582 | 91.311 | 90.041 | 88.770 |
| 95.767 | 94.503 | 93.238 | 91.973 | 90.709 | 89.444 | 88.179 | 86.914 | 85.650 |
| 85.778 | 84.612 | 83.447 | 82.282 | 81.116 | 79.951 | 78.785 | 77.620 | 76.454 |
| 68.449 | 67.491 | 66.533 | 65.576 | 64.618 | 63.661 | 62.703 | 61.746 | 60.788 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 60.00
ENDING TIME = 70.00
AVERAGE TEMPERATURE =113.499
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

Table III. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7.764 | 139.286 | 137.795 | 136.310 | 134.826 | 133.341 | 131.857 | 130.372 | 128.888 |
| 9.223 | 137.721 | 136.219 | 134.717 | 133.215 | 131.713 | 130.211 | 128.709 | 127.207 |
| 36.659 | 135.150 | 133.641 | 132.133 | 130.624 | 129.115 | 127.606 | 126.097 | 124.589 |
| 34.770 | 133.246 | 131.722 | 130.199 | 128.675 | 127.152 | 125.628 | 124.104 | 122.581 |
| 32.393 | 130.860 | 129.326 | 127.793 | 126.259 | 124.726 | 123.192 | 121.658 | 120.125 |
| 31.018 | 129.462 | 127.906 | 126.351 | 124.795 | 123.239 | 121.683 | 120.127 | 118.571 |
| 28.600 | 127.034 | 125.467 | 123.901 | 122.334 | 120.767 | 119.201 | 117.634 | 116.068 |
| 17.743 | 116.271 | 114.798 | 113.326 | 111.853 | 110.381 | 108.909 | 107.436 | 105.964 |
| 14.250 | 112.782 | 111.315 | 109.847 | 108.379 | 106.912 | 105.444 | 103.977 | 102.509 |
| 0.430 | 109.022 | 107.563 | 106.104 | 104.645 | 103.186 | 101.727 | 100.268 | 98.809 |
| 97.328 | 96.005 | 94.683 | 93.361 | 92.038 | 90.716 | 89.394 | 88.071 | 86.749 |
| 4.691 | 73.646 | 72.602 | 71.557 | 70.512 | 69.467 | 68.422 | 67.377 | 66.332 |

Table IV. Start-Up Process with Water Coolant (P=0 KPa, Re=3321).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 53.056
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 66.305 | 65.406 | 64.507 | 63.608 | 62.709 | 61.810 | 60.911 | 60.012 | 59.113 |
| 64.978 | 64.076 | 63.175 | 62.274 | 61.373 | 60.472 | 59.571 | 58.669 | 57.768 |
| 63.541 | 62.639 | 61.737 | 60.835 | 59.933 | 59.031 | 58.130 | 57.228 | 56.326 |
| 62.160 | 61.264 | 60.361 | 59.457 | 58.554 | 57.650 | 56.747 | 55.843 | 54.939 |
| 60.758 | 59.853 | 58.949 | 58.044 | 57.139 | 56.234 | 55.329 | 54.424 | 53.520 |
| 59.422 | 58.515 | 57.608 | 56.701 | 55.793 | 54.886 | 53.979 | 53.072 | 52.165 |
| 57.934 | 57.027 | 56.119 | 55.212 | 54.305 | 53.397 | 52.490 | 51.583 | 50.675 |
| 55.856 | 54.958 | 54.060 | 53.162 | 52.265 | 51.367 | 50.469 | 49.571 | 48.673 |
| 54.346 | 53.448 | 52.551 | 51.653 | 50.756 | 49.858 | 48.961 | 48.063 | 47.166 |
| 52.813 | 51.916 | 51.019 | 50.123 | 49.226 | 48.329 | 47.433 | 46.536 | 45.640 |
| 50.509 | 49.627 | 48.745 | 47.862 | 46.980 | 46.098 | 45.216 | 44.333 | 43.451 |
| 47.156 | 46.308 | 45.460 | 44.612 | 43.764 | 42.915 | 42.067 | 41.219 | 40.371 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 59.815
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 74.951 | 73.935 | 72.919 | 71.902 | 70.886 | 69.870 | 68.854 | 67.837 | 66.821 |
| 73.613 | 72.592 | 71.571 | 70.550 | 69.529 | 68.508 | 67.487 | 66.466 | 65.445 |
| 72.041 | 71.019 | 69.996 | 68.974 | 67.951 | 66.929 | 65.906 | 64.884 | 63.861 |
| 70.609 | 69.583 | 68.557 | 67.531 | 66.504 | 65.478 | 64.452 | 63.426 | 62.399 |
| 69.093 | 68.064 | 67.035 | 66.006 | 64.977 | 63.948 | 62.919 | 61.890 | 60.862 |
| 67.746 | 66.712 | 65.678 | 64.644 | 63.609 | 62.575 | 61.541 | 60.507 | 59.472 |
| 66.086 | 65.051 | 64.016 | 62.981 | 61.946 | 60.911 | 59.876 | 58.841 | 57.806 |
| 63.061 | 62.047 | 61.033 | 60.019 | 59.006 | 57.992 | 56.978 | 55.964 | 54.950 |

Table IV. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 61.322 | 60.309 | 59.297 | 58.284 | 57.271 | 56.258 | 55.246 | 54.233 | 53.220 |
| 59.533 | 58.523 | 57.512 | 56.501 | 55.491 | 54.480 | 53.469 | 52.458 | 51.448 |
| 56.018 | 55.040 | 54.061 | 53.083 | 52.104 | 51.126 | 50.147 | 49.169 | 48.191 |
| 50.280 | 49.376 | 48.472 | 47.568 | 46.663 | 45.759 | 44.855 | 43.950 | 43.046 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 30.00
ENDING TIME = 40.00
AVERAGE TEMPERATURE = 57.837
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 85.222 | 84.067 | 82.911 | 81.756 | 80.600 | 79.445 | 78.289 | 77.134 | 75.978 |
| 83.871 | 82.708 | 81.545 | 80.381 | 79.218 | 78.055 | 76.892 | 75.728 | 74.565 |
| 82.143 | 80.977 | 79.812 | 78.646 | 77.480 | 76.314 | 75.148 | 73.982 | 72.816 |
| 80.645 | 79.473 | 78.301 | 77.129 | 75.957 | 74.785 | 73.613 | 72.441 | 71.268 |
| 79.003 | 77.826 | 76.650 | 75.473 | 74.297 | 73.120 | 71.944 | 70.767 | 69.591 |
| 77.653 | 76.466 | 75.282 | 74.097 | 72.911 | 71.726 | 70.540 | 69.355 | 68.169 |
| 75.822 | 74.635 | 73.447 | 72.260 | 71.072 | 69.885 | 68.697 | 67.510 | 66.322 |
| 71.607 | 70.456 | 69.305 | 68.154 | 67.002 | 65.851 | 64.700 | 63.549 | 62.398 |
| 69.595 | 66.443 | 67.297 | 66.147 | 64.998 | 63.849 | 62.699 | 61.550 | 60.401 |
| 67.499 | 66.353 | 65.207 | 64.061 | 62.915 | 61.769 | 60.623 | 59.477 | 58.331 |
| 62.483 | 61.392 | 60.300 | 59.209 | 58.118 | 57.026 | 55.935 | 54.844 | 53.752 |
| 53.923 | 52.953 | 51.983 | 51.013 | 50.044 | 49.074 | 48.104 | 47.134 | 46.164 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 40.00
ENDING TIME = 50.00
AVERAGE TEMPERATURE = 77.391
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 97.471 | 96.150 | 94.828 | 93.507 | 92.185 | 90.863 | 89.542 | 88.220 | 86.899 |
| 96.103 | 94.770 | 93.437 | 92.104 | 90.771 | 89.438 | 88.106 | 86.773 | 85.440 |
| 94.194 | 92.857 | 91.520 | 90.183 | 88.846 | 87.509 | 86.172 | 84.835 | 83.498 |
| 92.623 | 91.277 | 89.931 | 88.585 | 87.238 | 85.892 | 84.546 | 83.200 | 81.854 |

Table IV. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 89.477 | 88.125 | 86.772 | 85.420 | 84.067 | 82.714 | 81.362 | 80.009 |
| [illegible] | 88.124 | 86.757 | 85.391 | 84.025 | 82.659 | 81.293 | 79.926 | 78.560 |
| [illegible] | 86.127 | 84.756 | 83.386 | 82.016 | 80.649 | 79.275 | 77.905 | 76.535 |
| [illegible] | 80.469 | 79.154 | 77.839 | 76.524 | 75.210 | 73.895 | 72.580 | [illegible] |
| [illegible] | 78.131 | 76.819 | 75.507 | 74.195 | 72.883 | 71.571 | 70.259 | 68.947 |
| 76.974 | 75.667 | 74.360 | 73.053 | 71.747 | 70.440 | 69.133 | 67.826 | 66.519 |
| 70.093 | 68.869 | 67.644 | 66.420 | 65.196 | 63.972 | 62.747 | 61.523 | 60.299 |
| 58.164 | 57.118 | 56.072 | 55.026 | 53.980 | 52.934 | 51.888 | 50.842 | 49.796 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME - 50.00
ENDING TIME - 60.00
AVERAGE TEMPERATURE - 88.815
PRESURE- 0.0 KPa
REYNOLD'S NUMBER- 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 112.137 | 110.616 | 109.096 | 107.575 | 106.055 | 104.534 | 103.014 | 101.494 | 99.973 |
| 110.745 | 109.210 | 107.674 | 106.138 | 104.602 | 103.066 | 101.530 | 99.994 | 98.458 |
| 108.627 | 107.085 | 105.543 | 104.002 | 102.460 | 100.918 | 99.376 | 97.834 | 96.292 |
| 106.975 | 105.420 | 103.866 | 102.311 | 100.756 | 99.201 | 97.646 | 96.092 | 94.537 |
| 105.002 | 103.438 | 101.875 | 100.311 | 98.747 | 97.184 | 95.620 | 94.056 | 92.493 |
| 103.687 | 102.104 | 100.521 | 98.938 | 97.355 | 95.772 | 94.189 | 92.606 | 91.023 |
| 101.555 | 99.965 | 98.374 | 96.784 | 95.193 | 93.603 | 92.012 | 90.422 | 88.831 |
| 93.948 | 92.437 | 90.927 | 89.416 | 87.906 | 86.396 | 84.885 | 83.375 | 81.865 |
| 91.210 | 89.704 | 88.197 | 86.691 | 85.185 | 83.678 | 82.172 | 80.666 | 79.159 |
| 88.288 | 86.789 | 85.290 | 83.791 | 82.292 | 80.793 | 79.295 | 77.796 | 76.297 |
| 79.079 | 77.698 | 76.316 | 74.935 | 73.554 | 72.173 | 70.791 | 69.410 | 68.029 |
| 63.103 | 61.968 | 60.833 | 59.698 | 58.564 | 57.429 | 56.294 | 55.159 | 54.024 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME - 60.00
ENDING TIME - 70.00
AVERAGE TEMPERATURE -102.529
PRESURE- 0.0 KPa
REYNOLD'S NUMBER- 0.33210E+04
COOLANT:WATER

Table IV. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 129.767 | 128.008 | 126.248 | 124.489 | 122.729 | 120.970 | 119.210 | 117.451 | 115.691 |
| 128.346 | 126.566 | 124.786 | 123.006 | 121.226 | 119.446 | 117.666 | 115.886 | 114.105 |
| 125.983 | 124.195 | 122.407 | 120.619 | 118.831 | 117.042 | 115.754 | 113.466 | 111.678 |
| 124.242 | 122.436 | 120.630 | 118.825 | 117.019 | 115.213 | 113.407 | 111.602 | 109.796 |
| 122.051 | 120.234 | 118.416 | 116.599 | 114.781 | 112.964 | 111.146 | 109.329 | 107.511 |
| 120.764 | 118.940 | 117.096 | 115.252 | 113.408 | 111.564 | 109.720 | 107.876 | 106.032 |
| 118.556 | 116.699 | 114.842 | 112.985 | 111.129 | 109.272 | 107.415 | 105.559 | 103.702 |
| 108.547 | 106.801 | 105.056 | 103.311 | 101.565 | 99.821 | 98.076 | 96.331 | 94.586 |
| 105.327 | 103.587 | 101.848 | 100.108 | 98.369 | 96.630 | 94.890 | 93.151 | 91.411 |
| 101.852 | 100.123 | 98.394 | 96.664 | 94.935 | 93.206 | 91.477 | 89.748 | 88.019 |
| 89.727 | 88.159 | 86.592 | 85.025 | 83.456 | 81.891 | 80.323 | 78.756 | 77.189 |
| 68.858 | 67.620 | 66.382 | 65.143 | 63.905 | 62.666 | 61.428 | 60.190 | 58.951 |

Table V. Start-Up Process with Water Coolant . . (P=3500 KPa, Re=6167).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 48.874
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT.WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 64.058 | 63.195 | 62.332 | 61.469 | 60.606 | 59.742 | 58.879 | 58.016 | 57.153 |
| 62.330 | 61.465 | 60.600 | 59.735 | 58.870 | 58.005 | 57.140 | 56.274 | 55.409 |
| 60.497 | 59.631 | 58.765 | 57.900 | 57.034 | 56.168 | 55.302 | 54.436 | 53.570 |
| 58.723 | 57.856 | 56.988 | 56.121 | 55.253 | 54.386 | 53.519 | 52.651 | 51.784 |
| 56.913 | 56.044 | 55.175 | 54.307 | 53.438 | 52.570 | 51.701 | 50.833 | 49.964 |
| 55.170 | 54.299 | 53.428 | 52.557 | 51.686 | 50.815 | 49.944 | 49.074 | 48.203 |
| 53.284 | 52.413 | 51.542 | 50.671 | 49.800 | 48.929 | 48.056 | 47.187 | 46.316 |
| 50.861 | 49.999 | 49.137 | 48.275 | 47.413 | 46.551 | 45.689 | 44.827 | 43.965 |
| 48.961 | 48.099 | 47.237 | 46.376 | 45.514 | 44.653 | 43.791 | 42.929 | 42.068 |
| 47.041 | 46.180 | 45.319 | 44.458 | 43.598 | 42.737 | 41.876 | 41.015 | 40.155 |
| 44.444 | 43.597 | 42.750 | 41.903 | 41.056 | 40.209 | 39.362 | 38.515 | 37.668 |
| [illegible] | 40.140 | 39.326 | 38.512 | 37.698 | 36.883 | 36.069 | 35.255 | 34.441 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 55.121
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 72.410 | 71.435 | 70.459 | 69.484 | 68.508 | 67.532 | 66.557 | 65.581 | 64.606 |
| 70.614 | 69.634 | 68.654 | 67.674 | 66.693 | 65.713 | 64.733 | 63.753 | 62.773 |
| 68.590 | 67.609 | 66.627 | 65.645 | 64.664 | 63.682 | 62.700 | 61.719 | 60.737 |
| 66.697 | 65.712 | 64.726 | 63.741 | 62.756 | 61.771 | 60.785 | 59.800 | 58.815 |
| 64.720 | 63.732 | 62.744 | 61.757 | 60.769 | 59.781 | 56.794 | 57.806 | 56.818 |
| 62.898 | 61.905 | 60.912 | 59.920 | 58.927 | 57.934 | 56.941 | 55.948 | 54.955 |
| 60.782 | 59.788 | 58.794 | 57.801 | 56.807 | 55.814 | 54.820 | 53.827 | 52.833 |
| 57.422 | 56.448 | 55.475 | 54.502 | 53.529 | 52.555 | 51.582 | 50.609 | 49.636 |

Table V. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 54.273 | 53.301 | 52.329 | 51.357 | 50.385 | 49.413 | 48.440 | 47.468 |
| [illegible] | 52.057 | 51.088 | 50.119 | 49.146 | 48.176 | 47.205 | 46.235 | 45.265 |
| [illegible] | 48.352 | 47.413 | 46.473 | 45.534 | 44.595 | 43.656 | 42.716 | 41.777 |
| [illegible] | 42.800 | 41.932 | 41.063 | 40.195 | 39.327 | 38.459 | 37.591 | 36.723 |

ELECTRODE TEMPERATURE DISTRIBÖTION
STARTING TIME - 30.00
ENDING TIME - 40.00
AVERAGE TEMPERATURE - 62.536
PRESURE- 3500.0 KPa
REYNOLD'S NUMBER- 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 82.334 | 81.224 | 80.115 | 79.006 | 77.896 | 76.787 | 75.678 | 74.569 | 73.459 |
| 80.454 | 79.337 | 78.221 | 77.104 | 75.987 | 74.871 | 73.754 | 72.637 | 71.520 |
| 78.208 | 77.089 | 75.970 | 74.850 | 73.731 | 72.612 | 71.493 | 70.373 | 69.254 |
| 76.177 | 75.051 | 73.926 | 72.801 | 71.676 | 70.550 | 69.425 | 68.300 | 67.175 |
| 74.003 | 72.873 | 71.744 | 70.614 | 69.485 | 68.356 | 67.226 | 66.097 | 64.967 |
| 72.095 | 70.958 | 69.820 | 68.682 | 67.544 | 66.406 | 65.268 | 64.130 | 62.992 |
| 69.736 | 68.596 | 67.456 | 66.316 | 65.176 | 64.036 | 62.897 | 61.757 | 60.617 |
| 65.204 | 64.099 | 62.993 | 61.888 | 60.783 | 59.678 | 58.573 | 57.468 | 56.363 |
| 62.699 | 61.596 | 60.493 | 59.389 | 58.286 | 57.183 | 56.079 | 54.975 | 53.872 |
| 60.122 | 59.022 | 57.922 | 56.822 | 55.721 | 54.621 | 53.521 | 52.421 | 51.321 |
| 54.980 | 53.932 | 52.885 | 51.837 | 50.789 | 49.742 | 48.694 | 47.646 | 46.598 |
| 46.831 | 45.900 | 44.969 | 44.038 | 43.107 | 42.176 | 41.245 | 40.314 | 39.383 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME - 40.00
ENDING TIME - 50.00
AVERAGE TEMPERATURE - 71.369
PRESURE- 3500.0 KPa
REYNOLD'S NUMBER- 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 94.167 | 92.899 | 91.630 | 90.361 | 89.092 | 87.824 | 86.555 | 85.286 | 84.017 |
| 92.187 | 90.908 | 89.628 | 88.349 | 87.069 | 85.790 | 84.510 | 83.231 | 81.951 |
| 89.682 | 88.398 | 87.115 | 85.831 | 84.548 | 83.264 | 81.981 | 80.697 | 79.414 |
| 87.491 | 86.198 | 84.906 | 83.614 | 82.321 | 81.029 | 79.737 | 78.444 | 77.152 |

Table V. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 83.753 | 82.405 | 81.186 | 79.898 | 78.569 | 77.291 | 75.997 | 74.69[illegible] |
| 83.086 | 81.774 | 80.463 | 79.151 | 77.839 | 76.528 | 75.216 | 73.905 | 72.593 |
| 80.474 | 79.159 | 77.843 | 76.528 | 75.212 | 73.897 | 72.581 | 71.266 | 69.950 |
| [illegible].470 | 73.208 | 71.946 | 70.683 | 69.421 | 68.159 | 66.897 | 65.635 | 64.372 |
| 71.571 | 70.312 | 69.052 | 67.793 | 66.533 | 65.274 | 64.014 | 62.755 | 61.495 |
| 68.561 | 67.307 | 66.052 | 64.798 | 63.543 | 62.289 | 61.034 | 59.780 | 58.525 |
| 61.676 | 60.501 | 59.325 | 58.150 | 56.975 | 55.799 | 54.624 | 53.449 | 52.274 |
| 50.515 | 49.511 | 48.506 | 47.502 | 46.498 | 45.494 | 44.489 | 43.485 | 42.481 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 50.00
ENDING TIME = 60.00
AVERAGE TEMPERATURE = 81.932
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 108.336 | 106.876 | 105.416 | 103.957 | 102.497 | 101.037 | 99.578 | 98.118 | 96.658 |
| 106.234 | 104.759 | 103.285 | 101.810 | 100.336 | 98.861 | 97.387 | 95.912 | 94.438 |
| 103.423 | 101.943 | 100.463 | 98.983 | 97.503 | 96.023 | 94.542 | 93.062 | 91.582 |
| 101.047 | 99.555 | 98.062 | 96.570 | 95.077 | 93.584 | 92.092 | 90.599 | 89.106 |
| 98.356 | 96.855 | 95.354 | 93.853 | 92.352 | 90.851 | 89.350 | 87.849 | 86.348 |
| 96.267 | 94.747 | 93.227 | 91.708 | 90.188 | 88.668 | 87.149 | 85.629 | 84.110 |
| 93.404 | 91.877 | 90.350 | 88.823 | 87.297 | 85.770 | 84.243 | 82.716 | 81.189 |
| 85.546 | 84.096 | 82.646 | 81.196 | 79.746 | 78.297 | 76.847 | 75.397 | 73.947 |
| 82.172 | 80.726 | 79.280 | 77.834 | 76.388 | 74.942 | 73.496 | 72.050 | 70.604 |
| 78.639 | 77.200 | 75.761 | 74.322 | 72.883 | 71.444 | 70.005 | 68.566 | 67.127 |
| 69.583 | 68.257 | 66.931 | 65.605 | 64.279 | 62.953 | 61.627 | 60.301 | 58.975 |
| 54.804 | 53.715 | 52.625 | 51.536 | 50.446 | 49.357 | 48.267 | 47.178 | 46.088 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 60.00
ENDING TIME = 70.00
AVERAGE TEMPERATURE = 94.613
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

Table V. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 125.369 | 123.679 | 121.990 | 120.301 | 118.612 | 116.923 | 115.234 | 113.545 | 111.856 |
| 123.119 | 121.409 | 119.700 | 117.991 | 116.282 | 114.573 | 112.864 | 111.156 | 109.447 |
| 119.948 | 118.232 | 116.515 | 114.798 | 113.082 | 111.365 | 109.648 | 107.931 | 106.215 |
| 117.357 | 115.624 | 113.890 | 112.157 | 110.423 | 108.690 | 106.956 | 105.223 | 103.489 |
| 114.327 | 112.582 | 110.837 | 109.092 | 107.348 | 105.603 | 103.858 | 102.113 | 100.368 |
| 112.141 | 110.370 | 108.600 | 106.830 | 105.060 | 103.290 | 101.519 | 99.749 | 97.979 |
| 109.040 | 107.257 | 105.475 | 103.693 | 101.910 | 100.126 | 98.345 | 96.563 | 94.780 |
| 98.840 | 97.164 | 95.469 | 93.814 | 92.139 | 90.463 | 88.788 | 87.113 | 85.438 |
| 94.890 | 93.220 | 91.550 | 89.881 | 88.211 | 86.541 | 84.871 | 83.201 | 81.531 |
| 90.721 | 89.061 | 87.401 | 85.741 | 84.081 | 82.421 | 80.761 | 79.101 | 77.441 |
| 78.952 | 77.448 | 75.943 | 74.439 | 72.934 | 71.430 | 69.925 | 68.420 | 66.915 |
| 59.803 | 58.614 | 57.425 | 56.236 | 55.047 | 53.858 | 52.669 | 51.481 | 50.292 |

Table VI. Start-Up Process with Water Coolant .
(P=0 KPa, Re=6167).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 39.696
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 52.820 | 52.095 | 51.370 | 50.645 | 49.921 | 49.196 | 48.471 | 47.746 | 47.021 |
| 51.297 | 50.570 | 49.843 | 49.117 | 48.390 | 47.664 | 46.937 | 46.210 | 45.484 |
| 49.685 | 48.958 | 48.231 | 47.504 | 46.777 | 46.050 | 45.323 | 44.595 | 43.868 |
| 48.123 | 47.395 | 46.666 | 45.938 | 45.209 | 44.481 | 43.752 | 43.024 | 42.295 |
| 46.530 | 45.801 | 45.071 | 44.342 | 43.612 | 42.883 | 42.153 | 41.424 | 40.695 |
| 44.992 | 44.261 | 43.530 | 42.798 | 42 057 | 41.335 | 40.604 | 39.873 | 39.141 |
| 43.338 | 42.605 | 41.875 | 41.145 | 40.411 | 39.680 | 38.948 | 38.217 | 37.485 |
| 41.247 | 40.523 | 39.799 | 39.075 | 38.351 | 37.627 | 36.903 | 36.179 | 35.455 |
| 39.581 | 38.858 | 38.135 | 37.411 | 36.687 | 35.964 | 35.240 | 34.516 | 33.793 |
| 37.901 | 37.178 | 36.455 | 35.732 | 35.009 | 34.286 | 33.563 | 32.841 | 32.118 |
| 35.677 | 34.965 | 34.254 | 33.543 | 32.832 | 32.120 | 31.409 | 30.698 | 29.986 |
| 32.741 | 32.060 | 31.376 | 30.692 | 30.009 | 29.325 | 28.641 | 27.957 | 27.271 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 44.768
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 59.707 | 58.888 | 58.069 | 57.249 | 56.430 | 55.611 | 54.791 | 53.972 | 53.152 |
| 58.114 | 57.291 | 56.467 | 55.644 | 54.821 | 53.998 | 53.175 | 52.352 | 51.529 |
| 56.332 | 55.508 | 54.684 | 53.859 | 53.035 | 52.210 | 51.386 | 50.561 | 49.737 |
| 54.657 | 53.830 | 53.003 | 52.175 | 51.348 | 50.520 | 49.693 | 48.865 | 48.038 |
| 52.913 | 52.084 | 51.254 | 50.425 | 49.595 | 48.766 | 47.936 | 47.107 | 46.277 |
| 51.295 | 50.461 | 49.627 | 48.794 | 47.960 | 47.126 | 46.292 | 45.458 | 44.624 |
| 49.436 | 48.601 | 47.767 | 46.932 | 46.098 | 45.263 | 44.429 | 43.594 | 42.760 |
| 46.568 | 45.750 | 44.933 | 44.115 | 43.298 | 42.481 | 41.663 | 40.846 | 40.029 |

Table VI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 43.846 | 43.030 | 42.213 | 41.397 | 40.580 | 39.764 | 38.947 | 38.131 |
| 42.724 | 41.909 | 41.094 | 40.279 | 39.465 | 38.650 | 37.835 | 37.020 | 36.205 |
| 39.569 | 38.779 | 37.990 | 37.201 | 36.413 | 35.624 | 34.835 | 34.046 | 33.257 |
| 34.913 | 34.184 | 33.455 | 32.726 | 31.997 | 31.268 | 30.539 | 29.810 | 29.081 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 30.00
ENDING TIME = 40.00
AVERAGE TEMPERATURE = 50.796
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 66.958 | 66.026 | 65.095 | 64.163 | 63.231 | 62.300 | 61.368 | 60.437 |
| 66.212 | 65.274 | 64.336 | 63.398 | 62.460 | 61.523 | 60.585 | 59.647 | 58.709 |
| 64.232 | 63.292 | 62.352 | 61.412 | 60.472 | 59.531 | 58.591 | 57.651 | 56.711 |
| 62.426 | 61.481 | 60.536 | 59.591 | 58.646 | 57.701 | 56.756 | 55.811 | 54.866 |
| 60.503 | 59.554 | 58.606 | 57.657 | 56.709 | 55.760 | 54.812 | 53.863 | 52.914 |
| [illegible] | 57.841 | 56.885 | 55.929 | 54.973 | 54.017 | 53.062 | 52.106 | 51.150 |
| [illegible] | 55.761 | 54.804 | 53.847 | 52.889 | 51.932 | 50.974 | 50.017 | 49.060 |
| 52.879 | 51.951 | 51.022 | 50.094 | 49.166 | 48.238 | 47.310 | 46.382 | 45.454 |
| 50.689 | 49.762 | 48.835 | 47.909 | 46.982 | 46.055 | 45.129 | 44.202 | 43.275 |
| 48.440 | 47.517 | 46.593 | 45.669 | 44.745 | 43.821 | 42.897 | 41.973 | 41.049 |
| 44.135 | 43.255 | 42.375 | 41.495 | 40.615 | 39.735 | 38.855 | 37.975 | 37.095 |
| 37.442 | 36.660 | 35.879 | 35.097 | 34.315 | 33.533 | 32.751 | 31.969 | 31.187 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 40.00
ENDING TIME = 50.00
AVERAGE TEMPERATURE = 57.977
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61570E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 77.647 | 76.582 | 75.516 | 74.451 | 73.385 | 72.320 | 71.254 | 70.189 | 69.123 |
| 75.868 | 74.794 | 73.719 | 72.644 | 71.570 | 70.495 | 69.420 | 68.346 | 67.271 |
| 73.655 | 72.577 | 71.499 | 70.421 | 69.343 | 68.265 | 67.187 | 66.109 | 65.031 |
| 71.698 | 70.613 | 69.527 | 68.442 | 67.356 | 66.271 | 65.186 | 64.100 | 63.015 |

Table VI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 68.470 | 67.379 | 66.289 | 65.198 | 64.108 | 63.017 | 61.927 | 60.836 |
| [illegible] | 66.657 | 65.556 | 64.454 | 63.353 | 62.251 | 61.150 | 60.048 | 58.947 |
| 65.452 | 64.347 | 63.243 | 62.138 | 61.033 | 59.928 | 58.823 | 57.719 | 56.614 |
| [illegible] | 59.333 | 58.273 | 57.213 | 56.153 | 55.093 | 54.033 | 52.973 | 51.913 |
| [illegible] | 56.803 | 55.746 | 54.688 | 53.630 | 52.572 | 51.514 | 50.457 | 49.399 |
| 55.240 | 54.186 | 53.133 | 52.079 | 51.026 | 49.972 | 48.918 | 47.865 | 46.811 |
| 49.510 | 48.523 | 47.536 | 46.549 | 45.561 | 44.574 | 43.587 | 42.600 | 41.613 |
| 40.388 | 39.544 | 38.701 | 37.857 | 37.014 | 36.171 | 35.327 | 34.484 | 33.640 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 50.00
ENDING TIME = 60.00
AVERAGE TEMPERATURE = 66.564
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61570E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 89.330 | 88.104 | 86.878 | 85.652 | 84.427 | 83.201 | 81.975 | 80.749 | 79.523 |
| 87.428 | 86.190 | 84.951 | 83.713 | 82.475 | 81.236 | 79.998 | 78.759 | 77.521 |
| 84.940 | 83.697 | 82.454 | 81.211 | 79.968 | 78.725 | 77.482 | 76.239 | 74.996 |
| 82.806 | 81.554 | 80.300 | 79.047 | 77.793 | 76.540 | 75.286 | 74.033 | 72.779 |
| 80.414 | 79.153 | 77.892 | 76.632 | 75.371 | 74.110 | 72.850 | 71.589 | 70.328 |
| 78.508 | 77.232 | 75.955 | 74.679 | 73.403 | 72.127 | 70.850 | 69.574 | 68.298 |
| 75.969 | 74.686 | 73.404 | 72.122 | 70.839 | 69.557 | 68.275 | 66.992 | 65.710 |
| 69.376 | 68.158 | 66.941 | 65.723 | 64.505 | 63.287 | 62.070 | 60.852 | 59.634 |
| 56.431 | 65.217 | 64.002 | 62.788 | 61.573 | 60.359 | 59.145 | 57.930 | 56.716 |
| 63.350 | 62.151 | 60.943 | 59.734 | 58.526 | 57.317 | 56.109 | 54.900 | 53.692 |
| 55.857 | 54.743 | 53.630 | 52.516 | 51.402 | 50.289 | 49.175 | 48.062 | 46.948 |
| 43.817 | 42.902 | 41.987 | 41.072 | 40.157 | 39.242 | 38.327 | 37.412 | 36.497 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 60.00
ENDING TIME = 70.00
AVERAGE TEMPERATURE = 75.874
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

Table VI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible].375 | 101.956 | 100.538 | 99.119 | 97.700 | 96.282 | 94.863 | 93.445 | 92.026 |
| [illegible].323 | 99.898 | 98.453 | 97.017 | 95.582 | 94.147 | 92.712 | 91.277 | 89.842 |
| 98.512 | 97.070 | 95.629 | 94.187 | 92.745 | 91.303 | 89.862 | 88.420 | 86.978 |
| 96.173 | 94.718 | 93.262 | 91.806 | 90.350 | 88.894 | 87.438 | 85.982 | 84.526 |
| 93.471 | 92.005 | 90.540 | 89.075 | 87.609 | 86.144 | 84.579 | 83.213 | 81.748 |
| 91.454 | 89.967 | 88.480 | 86.994 | 85.507 | 84.020 | 82.533 | 81.047 | 79.560 |
| 88.535 | 87.109 | 85.692 | 84.195 | 82.698 | 81.201 | 79.704 | 78.207 | 76.710 |
| 80.157 | 78.750 | 77.343 | 75.936 | 74.529 | 73.122 | 71.715 | 70.308 | 68.901 |
| 76.713 | 75.311 | 73.908 | 72.506 | 71.103 | 69.701 | 68.299 | 66.896 | 65.494 |
| 73.094 | 71.700 | 70.306 | 68.911 | 67.517 | 66.123 | 64.729 | 63.335 | 61.941 |
| 63.376 | 62.114 | 60.851 | 59.587 | 58.324 | 57.060 | 55.797 | 54.532 | 53.269 |
| 47.813 | 46.815 | 45.816 | 44.818 | 43.819 | 42.821 | 41.823 | 40.824 | 39.826 |

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### 5.4.2 Shut-Down Process

The transient temperature distribution is exhibited by Table I to Table XII for the same cases considered in the previous section. Also, Figure 111 demonstrates the change of the average electrode temperature as a function of time during the considered shut down process. The average transient decrease in the average transient electrode temperature was $4.665 * 10^{-4}$ °C per KPa. In addition, the increase in the coolant mass flow rate was somewhat less effective in rapidly reducing the transient electrode temperature. Both of these negative behaviors of the cooling system is due to the accumulation of heat and also because the heat loss to the surrounding was eliminated absolutely by the assumptions.

Considering the test results for the oil coolant, the temperature distribution for the considered examples are demonstrated by sample Table III and Table IV in the Appendix. Figure 112 shows the average electrode temperature decrease during a shut-down process. The curves that represent the different cases are closer to each other and with higher incremental slope. The average temperature differential during a shut-down process was $2.146 * 10^{-4}$ °C/KPa.

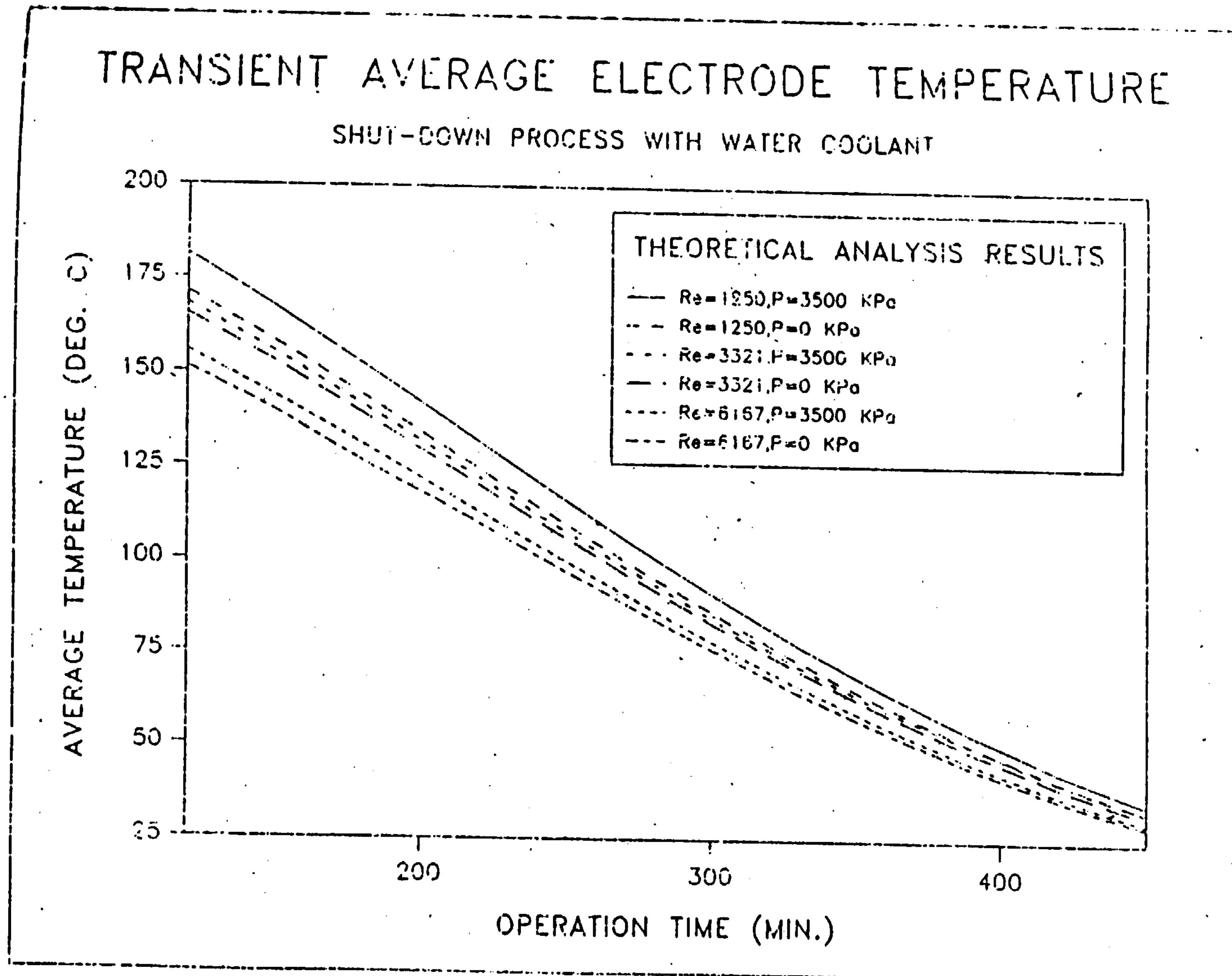


Figure 111. Theoretical Transient Average Electrode Temperature During Shut-Downs with Water Coolant.

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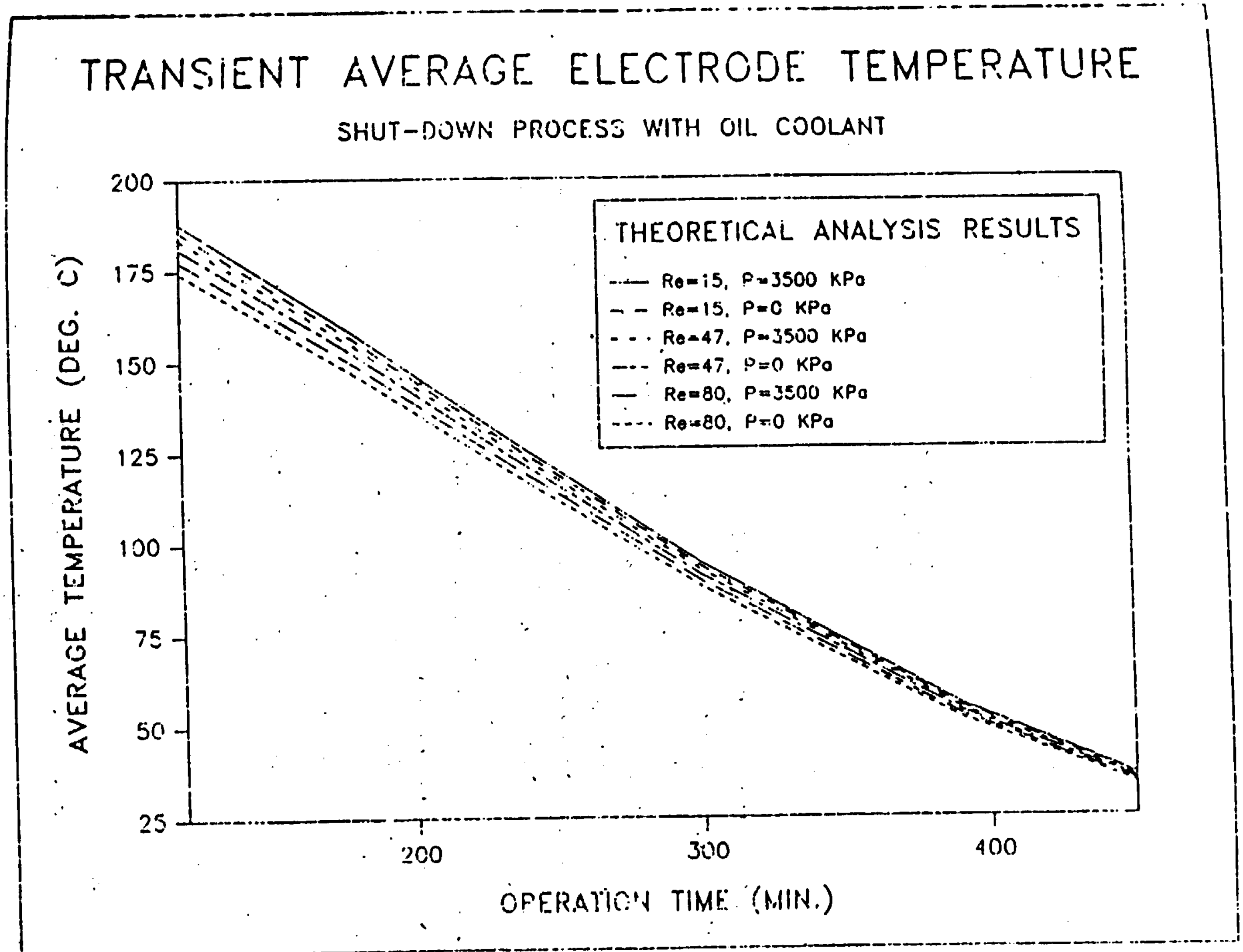


Figure 112. Theoretical Transient Average Electrode Temperature During Shut-Downs with Oil Coolant.

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Table VII. Shut-Down Process with Water Coolant (P=3500 KPa, Re=1250).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =150.00
AVERAGE TEMPERATURE =181.319
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 198.416 | 197.164 | 195.912 | 194.660 | 193.409 | 192.157 | 190.905 | 189.653 | 188.401 |
| 196.844 | 195.592 | 194.340 | 193.088 | 191.836 | 190.584 | 189.332 | 188.080 | 186.829 |
| 194.436 | 193.190 | 191.943 | 190.697 | 189.450 | 188.204 | 186.957 | 185.711 | 184.464 |
| 192.450 | 191.206 | 189.962 | 188.719 | 187.475 | 186.231 | 184.987 | 183.744 | 182.500 |
| 190.561 | 189.419 | 188.176 | 186.934 | 185.692 | 184.450 | 183.208 | 181.966 | 180.723 |
| 188.874 | 187.533 | 186.393 | 185.152 | 183.911 | 182.671 | 181.430 | 180.189 | 178.949 |
| 187.093 | 185.854 | 184.615 | 183.376 | 182.137 | 180.898 | 179.658 | 178.419 | 177.180 |
| 185.277 | 184.039 | 182.802 | 181.565 | 180.327 | 179.090 | 177.852 | 176.615 | 175.378 |
| .83.515 | 182.277 | 181.041 | 179.806 | 178.570 | 177.334 | 176.098 | 174.862 | 173.626 |
| .81.747 | 180.512 | 179.278 | 178.044 | 176.810 | 175.575 | 174.341 | 173.106 | 171.872 |
| .80.093 | 178.859 | 177.626 | 176.392 | 175.159 | 173.925 | 172.691 | 171.458 | 170.224 |
| .78.315 | 177.083 | 175.831 | 174.619 | 173.387 | 172.155 | 170.923 | 169.691 | 168.459 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =150.00
ENDING TIME =180.00
AVERAGE TEMPERATURE =167.440
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 85.249 | 184.080 | 182.911 | 181.743 | 180.574 | 179.405 | 178.236 | 177.067 | 175.898 |
| 83.772 | 182.604 | 181.435 | 180.266 | 179.098 | 177.929 | 176.760 | 175.591 | 174.423 |
| 80.506 | 179.349 | 178.192 | 177.035 | 175.878 | 174.721 | 173.563 | 172.406 | 171.249 |
| 78.208 | 177.056 | 175.904 | 174.753 | 173.601 | 172.449 | 171.298 | 170.146 | 168.994 |
| 76.281 | 175.133 | 173.984 | 172.836 | 171.687 | 170.539 | 169.390 | 168.242 | 167.093 |
| 74.359 | 173.214 | 172.069 | 170.923 | 169.778 | 168.633 | 167.488 | 166.342 | 165.197 |
| 72.451 | 171.309 | 170.167 | 169.025 | 167.883 | 166.741 | 165.599 | 164.456 | 163.314 |
| 70.470 | 169.331 | 168.193 | 167.055 | 165.916 | 164.778 | 163.639 | 162.501 | 161.362 |

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Table VII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible].599 | 167.464 | 166.329 | 165.193 | 164.058 | 162.922 | 161.787 | 160.651 | 159.516 |
| 166.724 | 165.592 | 164.460 | 163.327 | 162.195 | 161.062 | 159.930 | 158.798 | 157.665 |
| 1[illegible]5.08[illegible] | 163.950 | 162.819 | 161.688 | 160.557 | 159.427 | 158.296 | 157.165 | 156.03[illegible] |
| 1[illegible]3.181 | 162.054 | 160.926 | 159.799 | 158.671 | 157.544 | 156.416 | 155.289 | 154.18[illegible] |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =180.00
ENDING TIME =210.00
AVERAGE TEMPERATURE =152.461
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 170.903 | 169.827 | 168.749 | 167.670 | 166.592 | 165.514 | 164.435 | 163.357 | 162.279 |
| 169.534 | 168.456 | 167.378 | 166.299 | 165.221 | 164.143 | 163.065 | 161.987 | 160.909 |
| 165.370 | 164.310 | 163.250 | 162.190 | 161.130 | 160.070 | 159.010 | 157.949 | 156.889 |
| 162.795 | 161.743 | 160.691 | 159.639 | 158.587 | 157.535 | 156.483 | 155.431 | 154.379 |
| 160.740 | 159.693 | 158.646 | 157.598 | 156.551 | 155.504 | 154.457 | 153.410 | 152.362 |
| 158.6[illegible] | 157.651 | 156.609 | 155.566 | 154.524 | 153.481 | 152.439 | 151.397 | 150.354 |
| 156.669 | 155.631 | 154.594 | 153.556 | 152.518 | 151.481 | 150.443 | 149.406 | 148.368 |
| 154.535 | 153.503 | 152.471 | 151.438 | 150.406 | 149.374 | 148.342 | 147.310 | 146.278 |
| 152.570 | 151.542 | 150.515 | 149.487 | 148.460 | 147.432 | 146.405 | 145.377 | 144.350 |
| 150.599 | 149.576 | 148.553 | 147.530 | 146.507 | 145.484 | 144.462 | 143.439 | 142.416 |
| 148.977 | 147.957 | 146.936 | 145.916 | 144.895 | 143.875 | 142.854 | 141.834 | 140.813 |
| 146.972 | 145.956 | 144.941 | 143.925 | 142.910 | 141.894 | 140.879 | 139.864 | 138.848 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =210.00
ENDING TIME =240.00
AVERAGE TEMPERATURE =136.886
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 155.803 | 154.820 | 153.837 | 152.854 | 151.871 | 150.888 | 149.905 | 148.922 | 147.939 |
| 154.543 | 153.561 | 152.578 | 151.595 | 150.612 | 149.629 | 148.646 | 147.663 | 146.681 |
| 149.511 | 148.552 | 147.594 | 146.635 | 145.677 | 144.718 | 143.760 | 142.801 | 141.843 |
| [illegible]4[illegible].712 | 145.764 | 144.816 | 143.867 | 142.919 | 141.971 | 141.023 | 140.075 | 139.127 |

Table VII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 144.550 | 143.608 | 142.666 | 141.724 | 140.782 | 139.841 | 138.899 | 137.957 | 137.015 |
| 142.401 | 141.465 | 140.530 | 139.595 | 138.659 | 137.724 | 136.788 | 135.853 | 134.915 |
| 140.283 | 139.354 | 138.425 | 137.496 | 136.567 | 135.638 | 134.709 | 133.780 | 132.851 |
| 138.024 | 137.102 | 136.180 | 135.259 | 134.337 | 133.415 | 132.493 | 131.572 | 130.650 |
| 135.989 | 135.073 | 134.157 | 133.241 | 132.325 | 131.410 | 130.494 | 129.578 | 128.662 |
| 133.948 | 133.038 | 132.128 | 131.218 | 130.309 | 129.399 | 128.489 | 127.579 | 126.670 |
| 132.364 | 131.457 | 130.550 | 129.644 | 128.737 | 127.830 | 126.923 | 126.017 | 125.110 |
| 130.280 | 129.380 | 128.480 | 127.580 | 126.680 | 125.780 | 124.880 | 123.980 | 123.079 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =121.191
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 140.352 | 139.466 | 138.581 | 137.695 | 136.810 | 135.924 | 135.039 | 134.153 | 133.268 |
| 139.207 | 138.322 | 137.436 | 136.551 | 135.666 | 134.780 | 133.895 | 133.010 | 132.124 |
| 133.394 | 132.535 | 131.684 | 130.829 | 129.973 | 129.118 | 128.263 | 127.408 | 126.553 |
| 130.435 | 129.592 | 128.749 | 127.907 | 127.064 | 126.221 | 125.378 | 124.535 | 123.692 |
| 128.199 | 127.364 | 126.528 | 125.693 | 124.858 | 124.023 | 123.186 | 122.352 | 121.517 |
| 125.981 | 125.154 | 124.326 | 123.499 | 122.671 | 121.843 | 121.016 | 120.188 | 119.361 |
| 123.804 | 122.985 | 122.165 | 121.345 | 120.525 | 119.705 | 118.885 | 118.065 | 117.245 |
| 121.460 | 120.649 | 119.838 | 119.027 | 118.216 | 117.404 | 116.593 | 115.782 | 114.971 |
| 119.388 | 118.584 | 117.780 | 116.976 | 116.172 | 115.368 | 114.564 | 113.760 | 112.956 |
| 117.311 | 116.515 | 115.718 | 114.921 | 114.124 | 113.328 | 112.531 | 111.734 | 110.937 |
| 115.782 | 114.989 | 114.196 | 113.403 | 112.610 | 111.817 | 111.024 | 110.231 | 109.437 |
| 113.560 | 112.874 | 112.089 | 111.304 | 110.519 | 109.733 | 108.948 | 108.163 | 107.377 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE =105.807
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

Table VII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 124.146 | 123.358 | 122.569 | 121.781 | 120.993 | 120.205 | 119.416 | 118.628 |
| [illegible] | 123.117 | 122.329 | 121.541 | 120.753 | 119.965 | 119.177 | 118.389 | 117.601 |
| [illegible] | 116.696 | 115.943 | 115.190 | 114.437 | 113.685 | 112.932 | 112.179 | 111.426 |
| [illegible] | 113.662 | 112.923 | 112.184 | 111.444 | 110.705 | 109.966 | 109.226 | 108.487 |
| [illegible] | 111.400 | 110.670 | 109.939 | 109.209 | 108.478 | 107.748 | 107.017 | 106.287 |
| [illegible] | 109.163 | 108.442 | 107.720 | 106.998 | 106.276 | 105.554 | 104.833 | 104.111 |
| [illegible] | 106.976 | 106.263 | 105.550 | 104.837 | 104.123 | 103.410 | 102.697 | 101.984 |
| [illegible] | 104.605 | 103.902 | 103.199 | 102.496 | 101.792 | 101.089 | 100.386 | 99.682 |
| 103.239 | 102.543 | 101.848 | 101.153 | 100.458 | 99.762 | 99.067 | 98.372 | 97.676 |
| 101.157 | 100.479 | 99.792 | 99.105 | 98.418 | 97.731 | 97.044 | 96.357 | 95.670 |
| 99.711 | 99.028 | 98.345 | 97.661 | 96.978 | 96.295 | 95.612 | 94.929 | 94.246 |
| 97.592 | 96.918 | 96.244 | 95.569 | 94.895 | 94.221 | 93.547 | 92.872 | 92.198 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =300.00
ENDING TIME =330.00
AVERAGE TEMPERATURE = 91.099
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | 108.505 | 107.812 | 107.118 | 106.425 | 105.732 | 105.038 | 104.345 |
| [illegible] | 108.264 | 107.591 | 106.898 | 106.205 | 105.511 | 104.818 | 104.125 | 103.432 |
| [illegible] | 101.396 | 100.742 | 100.087 | 99.433 | 98.779 | 98.125 | 97.471 | 96.816 |
| 98.987 | 98.347 | 97.707 | 97.068 | 96.428 | 95.788 | 95.148 | 94.509 | 93.869 |
| 96.725 | 96.095 | 95.465 | 94.835 | 94.205 | 93.575 | 92.941 | 92.314 | 91.684 |
| 94.456 | 93.875 | 93.254 | 92.634 | 92.013 | 91.392 | 90.771 | 90.151 | 89.530 |
| 92.325 | 91.773 | 91.202 | 90.490 | 89.879 | 89.267 | 88.656 | 88.044 | 87.433 |
| 89.959 | 89.358 | 88.758 | 88.157 | 87.556 | 86.955 | 86.354 | 85.754 | 85.153 |
| 87.932 | 87.340 | 86.747 | 86.155 | 85.563 | 84.971 | 84.379 | 83.787 | 83.194 |
| 85.906 | 85.323 | 84.739 | 84.156 | 83.572 | 82.989 | 82.406 | 81.822 | 81.239 |
| 84.540 | 83.961 | 83.382 | 82.803 | 82.224 | 81.645 | 81.066 | 80.487 | 79.908 |
| [illegible] | 81.902 | 81.332 | 80.762 | 80.193 | 79.523 | 79.053 | 78.483 | 77.913 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =330.00

Table VII. Continued.

ENDING TIME =360.00
AVERAGE TEMPERATURE = 77.354
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5.515 | 94.912 | 94.310 | 93.707 | 93.104 | 92.502 | 91.899 | 91.296 | 90.694 |
| .710 | 94.108 | 93.505 | 92.903 | 92.301 | 91.698 | 91.096 | 90.494 | 89.891 |
| 7.504 | 86.943 | 86.382 | 85.821 | 85.260 | 84.699 | 84.138 | 83.577 | 83.016 |
| .494 | 83.948 | 83.402 | 82.856 | 82.310 | 81.764 | 81.218 | 80.672 | 80.126 |
| 2.297 | 81.751 | 81.215 | 80.678 | 80.142 | 79.606 | 79.070 | 78.534 | 77.998 |
| 0.117 | 79.591 | 79.065 | 78.538 | 78.012 | 77.486 | 76.960 | 76.433 | 75.907 |
| 8.013 | 77.497 | 76.980 | 76.463 | 75.947 | 75.430 | 74.913 | 74.397 | 73.880 |
| 5.714 | 75.208 | 74.703 | 74.197 | 73.692 | 73.186 | 72.680 | 72.175 | 71.669 |
| 3.769 | 73.272 | 72.775 | 72.279 | 71.782 | 71.285 | 70.788 | 70.291 | 69.794 |
| .830 | 71.342 | 70.854 | 70.366 | 69.878 | 69.391 | 68.903 | 68.415 | 67.927 |
| 9.569 | 70.086 | 69.602 | 69.119 | 68.635 | 68.152 | 67.669 | 67.185 | 66.702 |
| 8.593 | 68.119 | 67.645 | 67.171 | 66.697 | 66.223 | 65.749 | 65.275 | 64.801 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =360.00
ENDING TIME =390.00
AVERAGE TEMPERATURE = 64.732
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2.035 | 81.517 | 80.999 | 80.482 | 79.964 | 79.447 | 78.929 | 78.411 | 77.894 |
| 1.335 | 80.817 | 80.300 | 79.783 | 79.266 | 78.748 | 78.231 | 77.714 | 77.196 |
| 4.044 | 73.569 | 73.094 | 72.620 | 72.145 | 71.670 | 71.196 | 70.721 | 70.246 |
| 1.152 | 70.692 | 70.232 | 69.772 | 69.313 | 68.853 | 68.393 | 67.933 | 67.473 |
| 9.039 | 68.589 | 68.139 | 67.690 | 67.240 | 66.790 | 66.340 | 65.890 | 65.441 |
| 5.970 | 66.530 | 66.090 | 65.650 | 65.210 | 64.770 | 64.330 | 63.890 | 63.451 |
| 4.972 | 64.542 | 64.112 | 63.681 | 63.251 | 62.821 | 62.390 | 61.960 | 61.530 |
| 2.785 | 62.366 | 61.947 | 61.528 | 61.108 | 60.689 | 60.270 | 59.850 | 59.431 |
| 0.957 | 60.546 | 60.136 | 59.725 | 59.315 | 58.904 | 58.494 | 58.083 | 57.673 |
| 9.139 | 58.738 | 58.336 | 57.934 | 57.533 | 57.131 | 56.729 | 56.328 | 55.926 |

Table VII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 57.995 | 57.597 | 57.200 | 56.803 | 56.405 | 56.008 | 55.611 | 55.214 | 54.816 |
| 56.148 | 55.760 | 55.372 | 54.984 | 54.595 | 54.200 | 53.820 | 53.432 | 53.044 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 53.512
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 69.622 | 69.182 | 68.743 | 68.304 | 67.865 | 67.425 | 66.986 | 66.547 | 66.107 |
| 69.019 | 68.581 | 68.142 | 67.703 | 67.264 | 66.825 | 66.386 | 65.947 | 65.508 |
| 61.830 | 61.434 | 61.037 | 60.641 | 60.245 | 59.848 | 59.452 | 59.055 | 58.659 |
| 59.109 | 58.727 | 58.345 | 57.963 | 57.581 | 57.199 | 56.817 | 56.435 | 56.053 |
| 57.126 | 56.754 | 56.381 | 56.009 | 55.637 | 55.265 | 54.893 | 54.520 | 54.148 |
| 55.191 | 54.829 | 54.466 | 54.104 | 53.741 | 53.379 | 53.016 | 52.654 | 52.291 |
| 53.333 | 52.979 | 52.626 | 52.273 | 51.920 | 51.567 | 51.213 | 50.860 | 50.507 |
| 51.297 | 50.954 | 50.612 | 50.269 | 49.927 | 49.584 | 49.242 | 48.899 | 48.556 |
| 49.613 | 49.279 | 48.945 | 48.611 | 48.277 | 47.943 | 47.608 | 47.274 | 46.940 |
| 47.944 | 47.619 | 47.293 | 46.968 | 46.642 | 46.316 | 45.991 | 45.665 | 45.339 |
| 46.923 | 46.602 | 46.280 | 45.959 | 45.627 | 45.316 | 44.994 | 44.673 | 44.352 |
| 45.234 | 44.922 | 44.609 | 44.297 | 43.984 | 43.672 | 43.355 | 43.047 | 42.734 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =420.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 43.602
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 58.386 | 58.018 | 57.650 | 57.281 | 56.913 | 56.545 | 56.176 | 55.808 | 55.439 |
| 57.874 | 57.506 | 57.138 | 56.770 | 56.402 | 56.034 | 55.666 | 55.298 | 54.930 |
| 50.952 | 50.625 | 50.299 | 49.972 | 49.645 | 49.319 | 48.992 | 48.666 | 48.339 |
| 48.442 | 48.129 | 47.816 | 47.503 | 47.190 | 46.877 | 46.564 | 46.251 | 45.938 |
| 46.617 | 46.313 | 46.009 | 45.706 | 45.402 | 45.098 | 44.795 | 44.491 | 44.187 |
| 44.844 | 44.550 | 44.255 | 43.960 | 43.666 | 43.371 | 43.077 | 42.782 | 42.488 |

Table VII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 43.149 | 42.862 | 42.577 | 42.291 | 42.005 | 41.720 | 41.434 | 41.148 | 40.862 |
| 41.293 | 41.017 | 40.741 | 40.466 | 40.190 | 39.914 | 39.633 | 39.353 | 39.087 |
| 39.773 | 39.506 | 39.238 | 38.970 | 38.702 | 38.434 | 38.166 | 37.898 | 37.631 |
| 38.273 | 39.013 | 37.753 | 37.493 | 37.233 | 36.973 | 36.713 | 36.453 | 36.193 |
| 37.377 | 37.121 | 35.865 | 36.609 | 36.353 | 36.097 | 35.841 | 35.585 | 35.329 |
| 35.866 | 35.618 | 35.371 | 35.123 | 34.375 | 34.627 | 34.379 | 34.132 | 33.884 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 35.047
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 48.384 | 48.079 | 47.773 | 47.468 | 47.163 | 46.858 | 46.552 | 45.247 | 45.942 |
| 47.952 | 47.648 | 47.343 | 47.038 | 46.733 | 46.428 | 46.123 | 45.818 | 45.513 |
| 41.435 | 41.170 | 40.904 | 40.639 | 40.373 | 40.107 | 39.842 | 39.576 | 39.310 |
| 39.166 | 38.912 | 38.659 | 38.406 | 38.153 | 37.900 | 37.647 | 37.394 | 37.141 |
| 37.517 | 37.273 | 37.028 | 36.784 | 36.539 | 36.295 | 36.051 | 35.806 | 35.562 |
| 35.923 | 35.688 | 35.452 | 35.216 | 34.930 | 34.744 | 34.508 | 34.272 | 34.036 |
| 34.407 | 34.179 | 33.951 | 33.723 | 33.495 | 33.268 | 33.040 | 32.812 | 32.584 |
| 32.750 | 32.531 | 32.313 | 32.094 | 31.875 | 31.656 | 31.438 | 31.219 | 31.000 |
| 31.406 | 31.194 | 30.903 | 30.771 | 30.560 | 30.348 | 30.137 | 29.925 | 29.714 |
| 30.084 | 29.880 | 29.675 | 29.471 | 29.267 | 29.063 | 28.858 | 28.654 | 28.450 |
| 29.313 | 29.112 | 28.911 | 28.710 | 28.510 | 28.309 | 28.108 | 27.907 | 27.707 |
| 27.989 | 27.795 | 27.602 | 27.409 | 27.215 | 27.022 | 26.828 | 26.635 | 26.442 |

Table VIII. Shut-Down Process with Water Coolant (P=0 KPa, Re=1250).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =150.00
AVERAGE TEMPERATURE =171.316
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 188.968 | 187.910 | 186.851 | 185.793 | 184.735 | 183.677 | 182.618 | 181.560 | 180.502 |
| 187.084 | 186.025 | 184.967 | 183.909 | 182.851 | 181.793 | 180.735 | 179.676 | 178.618 |
| 184.408 | 183.354 | 182.301 | 181.247 | 180.194 | 179.140 | 178.086 | 177.033 | 175.979 |
| 182.134 | 181.083 | 180.031 | 178.980 | 177.929 | 176.878 | 175.826 | 174.775 | 173.724 |
| 180.049 | 178.998 | 177.948 | 176.898 | 175.843 | 174.798 | 173.748 | 172.698 | 171.648 |
| 177.965 | 176.917 | 175.868 | 174.819 | 173.771 | 172.722 | 171.673 | 170.625 | 169.576 |
| 175.890 | 174.842 | 173.795 | 172.747 | 171.700 | 170.652 | 169.605 | 168.558 | 167.510 |
| 173.781 | 172.735 | 171.689 | 170.643 | 169.597 | 168.551 | 167.505 | 166.460 | 165.414 |
| 171.723 | 170.679 | 169.634 | 168.589 | 167.545 | 166.500 | 165.455 | 164.411 | 163.366 |
| 169.664 | 168.621 | 167.577 | 166.534 | 165.490 | 164.447 | 163.404 | 162.360 | 161.317 |
| 167.710 | 166.668 | 165.625 | 164.582 | 163.539 | 162.496 | 161.454 | 160.411 | 159.368 |
| 165.642 | 164.600 | 163.559 | 162.517 | 161.476 | 160.435 | 159.393 | 158.352 | 157.310 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =150.00
ENDING TIME =180.00
AVERAGE TEMPERATURE =158.211
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 176.428 | 175.440 | 174.452 | 173.464 | 172.476 | 171.488 | 170.500 | 169.512 | 168.524 |
| 174.661 | 173.673 | 172.685 | 171.697 | 170.709 | 169.721 | 168.733 | 167.745 | 166.757 |
| 171.197 | 170.219 | 169.240 | 168.262 | 167.284 | 166.306 | 165.328 | 164.350 | 163.372 |
| 168.655 | 167.682 | 166.708 | 165.735 | 164.761 | 163.788 | 162.814 | 161.841 | 160.867 |
| 166.469 | 165.498 | 164.527 | 163.557 | 162.585 | 161.615 | 160.644 | 159.673 | 158.703 |
| 164.289 | 163.321 | 162.353 | 161.385 | 160.417 | 159.449 | 158.481 | 157.513 | 156.544 |
| 162.125 | 161.159 | 160.194 | 159.228 | 158.263 | 157.297 | 156.332 | 155.367 | 154.401 |
| 159.893 | 158.931 | 157.968 | 157.006 | 156.044 | 155.081 | 154.119 | 153.157 | 152.194 |

Table VIII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 157.760 | 156.808 | 155.848 | 154.888 | 153.929 | 152.969 | 152.009 | 151.049 | 150.089 |
| 155.640 | 154.683 | 153.726 | 152.768 | 151.811 | 150.854 | 149.897 | 148.940 | 147.983 |
| 153.730 | 152.774 | 151.818 | 150.862 | 149.907 | 148.951 | 147.995 | 147.039 | 146.083 |
| 151.583 | 150.630 | 149.677 | 148.724 | 147.771 | 146.818 | 145.865 | 144.912 | 143.959 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =180.00
ENDING TIME =210.00
AVERAGE TEMPERATURE =144.065
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 162.767 | 161.856 | 160.944 | 160.033 | 159.121 | 158.210 | 157.298 | 156.387 | 155.475 |
| 161.129 | 160.217 | 159.305 | 158.394 | 157.483 | 156.571 | 155.660 | 154.749 | 153.837 |
| 156.841 | 155.945 | 155.049 | 154.153 | 153.257 | 152.361 | 151.465 | 150.568 | 149.672 |
| 154.069 | 153.180 | 152.291 | 151.401 | 150.512 | 149.623 | 148.733 | 147.844 | 146.955 |
| 151.793 | 150.908 | 150.023 | 149.138 | 148.252 | 147.367 | 146.482 | 145.597 | 144.711 |
| 149.528 | 148.647 | 147.766 | 146.885 | 146.004 | 145.122 | 144.241 | 143.360 | 142.479 |
| 147.267 | 146.410 | 145.533 | 144.656 | 143.779 | 142.902 | 142.025 | 141.148 | 140.271 |
| 144.946 | 144.074 | 143.202 | 142.329 | 141.457 | 140.585 | 139.712 | 138.840 | 137.967 |
| 142.768 | 141.899 | 141.031 | 140.162 | 139.294 | 138.425 | 137.557 | 136.688 | 135.819 |
| 140.586 | 139.722 | 138.857 | 137.993 | 137.128 | 136.263 | 135.399 | 134.534 | 133.670 |
| 138.734 | 137.871 | 137.009 | 136.146 | 135.283 | 134.421 | 133.558 | 132.696 | 131.833 |
| 136.526 | 135.668 | 134.809 | 133.951 | 133.093 | 132.234 | 131.376 | 130.517 | 129.659 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =210.00
ENDING TIME =240.00
AVERAGE TEMPERATURE =129.358
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 148.384 | 147.553 | 146.722 | 145.891 | 145.060 | 144.229 | 143.398 | 142.567 | 141.737 |
| 146.881 | 146.050 | 145.219 | 144.389 | 143.558 | 142.727 | 141.896 | 141.065 | 140.235 |
| 141.800 | 140.989 | 140.179 | 139.369 | 138.559 | 137.749 | 136.939 | 136.129 | 135.319 |

Table VIII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 135.504 | 135.708 | 134.912 | 134.116 | 133.320 | 132.524 | 131.728 | 130.932 | 130.136 |
| 134.176 | 133.386 | 132.595 | 131.804 | 131.014 | 130.223 | 129.432 | 128.642 | 127.851 |
| 131.883 | 131.097 | 130.312 | 129.527 | 128.741 | 127.956 | 127.171 | 126.385 | 125.600 |
| 129.460 | 128.681 | 127.902 | 127.123 | 126.343 | 125.564 | 124.785 | 124.006 | 123.227 |
| 127.252 | 126.478 | 125.704 | 124.930 | 124.156 | 123.381 | 122.607 | 121.833 | 121.059 |
| 125.042 | 124.273 | 123.504 | 122.735 | 121.966 | 121.197 | 120.428 | 119.659 | 118.890 |
| 123.262 | 122.496 | 121.730 | 120.963 | 120.197 | 119.430 | 118.664 | 117.898 | 117.131 |
| 121.021 | 120.260 | 119.499 | 118.738 | 117.977 | 117.217 | 116.456 | 115.695 | 114.934 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =114.536
PRESURE= 0.0 KFa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT.WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 133.669 | 132.920 | 132.172 | 131.423 | 130.674 | 129.926 | 129.177 | 128.429 | 127.680 |
| 132.265 | 131.557 | 130.808 | 130.060 | 129.312 | 128.563 | 127.815 | 127.067 | 126.318 |
| 126.514 | 125.791 | 125.068 | 124.346 | 123.623 | 122.900 | 122.177 | 121.454 | 120.731 |
| 123.444 | 122.731 | 122.019 | 121.305 | 120.594 | 119.881 | 119.169 | 118.456 | 117.744 |
| 121.063 | 120.357 | 119.651 | 118.945 | 118.239 | 117.533 | 116.827 | 116.121 | 115.415 |
| 118.705 | 118.005 | 117.306 | 116.607 | 115.907 | 115.208 | 114.508 | 113.809 | 113.109 |
| 116.391 | 115.698 | 115.005 | 114.311 | 113.618 | 112.925 | 112.232 | 111.539 | 110.846 |
| 113.924 | 113.238 | 112.553 | 111.867 | 111.181 | 110.496 | 109.810 | 109.124 | 108.439 |
| 111.718 | 111.038 | 110.359 | 109.679 | 108.999 | 108.320 | 107.640 | 106.960 | 106.281 |
| 109.512 | 108.839 | 108.165 | 107.492 | 106.818 | 106.145 | 105.471 | 104.798 | 104.124 |
| 107.821 | 107.151 | 106.480 | 105.810 | 105.140 | 104.469 | 103.799 | 103.128 | 102.458 |
| 105.581 | 104.918 | 104.254 | 103.590 | 102.926 | 102.262 | 101.599 | 100.935 | 100.271 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE =100.006
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

Table VIII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 118.985 | 118.319 | 117.652 | 116.986 | 116.320 | 115.653 | 114.987 | 114.321 | 113.655 |
| 117.762 | 117.096 | 116.429 | 115.763 | 115.097 | 114.431 | 113.765 | 113.099 | 112.433 |
| 111.392 | 110.755 | 110.119 | 109.482 | 108.846 | 108.209 | 107.573 | 106.937 | 106.300 |
| 108.270 | 107.645 | 107.020 | 106.395 | 105.770 | 105.145 | 104.520 | 103.895 | 103.270 |
| 105.890 | 105.272 | 104.655 | 104.037 | 103.419 | 102.802 | 102.184 | 101.567 | 100.949 |
| 103.539 | 102.929 | 102.318 | 101.708 | 101.098 | 100.488 | 99.878 | 99.268 | 98.658 |
| 101.241 | 100.638 | 100.035 | 99.432 | 98.829 | 98.226 | 97.624 | 97.021 | 96.418 |
| 98.775 | 98.180 | 97.586 | 96.991 | 96.397 | 95.802 | 95.208 | 94.613 | 94.019 |
| 96.606 | 96.019 | 95.431 | 94.843 | 94.255 | 93.667 | 93.080 | 92.492 | 91.904 |
| 94.441 | 93.860 | 93.279 | 92.698 | 92.117 | 91.537 | 90.956 | 90.375 | 89.794 |
| 92.855 | 92.277 | 91.700 | 91.123 | 90.545 | 89.968 | 89.391 | 88.813 | 88.236 |
| 90.656 | 90.086 | 89.516 | 88.946 | 88.376 | 87.806 | 87.236 | 86.666 | 86.096 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =300.00
ENDING TIME =330.00
AVERAGE TEMPERATURE = 86.112
PRESURE= 0 0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 104.659 | 104.073 | 103.487 | 102.901 | 102.315 | 101.729 | 101.142 | 100.556 | 99.970 |
| 103.573 | 102.988 | 102.402 | 101.816 | 101.230 | 100.644 | 100.059 | 99.473 | 98.887 |
| 96.787 | 96.234 | 95.681 | 95.128 | 94.575 | 94.022 | 93.469 | 92.916 | 92.363 |
| 93.681 | 93.140 | 92.599 | 92.059 | 91.518 | 90.977 | 90.436 | 89.896 | 89.355 |
| 91.342 | 90.809 | 90.276 | 89.744 | 89.211 | 88.678 | 88.146 | 87.613 | 87.080 |
| 89.038 | 88.513 | 87.989 | 87.464 | 86.939 | 86.415 | 85.890 | 85.365 | 84.841 |
| 86.796 | 86.279 | 85.762 | 85.245 | 84.729 | 84.212 | 83.695 | 83.178 | 82.661 |
| 84.377 | 83.870 | 83.362 | 82.854 | 82.346 | 81.838 | 81.331 | 80.823 | 80.315 |
| 82.283 | 81.782 | 81.281 | 80.781 | 80.280 | 79.780 | 79.279 | 78.779 | 78.278 |
| 80.195 | 79.702 | 79.209 | 78.715 | 78.222 | 77.729 | 77.236 | 76.743 | 76.249 |
| 78.728 | 78.238 | 77.749 | 77.259 | 76.770 | 76.280 | 75.791 | 75.301 | 74.812 |
| 76.610 | 76.129 | 75.647 | 75.165 | 74.684 | 74.202 | 73.720 | 73.239 | 72.757 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =330.00

Table VIII. Continued.

ENDING TIME =330.00
AVERAGE TEMPERATURE = 73.125
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 90.966 | 90.457 | 89.948 | 89.438 | 88.929 | 88.419 | 87.910 | 87.401 | 86.891 |
| 90.014 | 89.505 | 88.996 | 88.487 | 87.978 | 87.468 | 86.959 | 86.450 | 85.941 |
| 82.991 | 82.516 | 82.042 | 81.568 | 81.094 | 60.620 | 60.145 | 79.671 | 79.197 |
| 79.965 | 79.504 | 79.042 | 78.581 | 78.119 | 77.658 | 77.196 | 76.734 | 76.273 |
| 77.707 | 77.253 | 76.800 | 76.347 | 75.894 | 75.441 | 74.988 | 74.534 | 74.081 |
| 73.490 | 75.045 | 74.600 | 74.155 | 73.711 | 73.266 | 72.821 | 72.376 | 71.931 |
| 73.342 | 72.905 | 72.468 | 72.032 | 71.595 | 71.158 | 70.721 | 70.285 | 69.848 |
| 71.016 | 70.589 | 70.161 | 69.734 | 69.307 | 68.879 | 68.452 | 68.024 | 67.597 |
| 69.030 | 68.610 | 68.190 | 67.770 | 67.350 | 66.930 | 66.510 | 66.090 | 65.670 |
| 67.054 | 66.642 | 66.230 | 65.817 | 65.405 | 64.992 | 64.580 | 64.168 | 63.755 |
| 65.717 | 65.308 | 64.899 | 64.491 | 64.082 | 63.674 | 63.265 | 62.856 | 62.448 |
| 63.716 | 63.317 | 62.916 | 62.515 | 62.115 | 61.715 | 61.314 | 60.913 | 60.513 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =360.00
ENDING TIME =390.00
AVERAGE TEMPERATURE = 61.251
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 78.128 | 77.691 | 77.253 | 76.816 | 76.378 | 75.941 | 75.503 | 75.066 | 74.628 |
| 77.302 | 76.865 | 76.427 | 75.990 | 75.553 | 75.116 | 74.678 | 74.241 | 73.804 |
| 70.225 | 69.824 | 69.422 | 69.021 | 68.620 | 68.219 | 67.817 | 67.416 | 67.015 |
| 67.338 | 66.949 | 66.561 | 66.172 | 65.783 | 65.395 | 65.006 | 64.617 | 64.229 |
| 65.196 | 64.816 | 64.436 | 64.055 | 63.675 | 63.295 | 62.915 | 62.535 | 62.154 |
| 63.102 | 62.730 | 62.358 | 61.986 | 61.615 | 61.243 | 60.871 | 60.499 | 60.127 |
| 61.082 | 60.718 | 60.354 | 59.990 | 59.627 | 59.263 | 58.899 | 58.535 | 58.172 |
| 58.890 | 58.535 | 58.181 | 57.827 | 57.472 | 57.118 | 56.763 | 56.409 | 56.054 |
| 57.041 | 56.694 | 56.347 | 56.000 | 55.653 | 55.306 | 54.959 | 54.612 | 54.265 |
| 55.207 | 54.868 | 54.528 | 54.189 | 53.849 | 53.510 | 53.170 | 52.831 | 52.491 |

Table VIII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 53.671 | 53.335 | 53.000 | 52.664 | 52.328 | 51.992 | 51.656 | 51.321 |
| [illegible] | 51.829 | 51.501 | 51.173 | 50.845 | 50.517 | 50.190 | 49.862 | 49.534 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 50.602
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 66.306 | 65.935 | 65.564 | 65.192 | 64.821 | 64.450 | 64.078 | 63.707 | 63.336 |
| 65.597 | 65.226 | 64.855 | 64.484 | 64.113 | 63.742 | 63.371 | 63.000 | 62.629 |
| 58.641 | 58.306 | 57.971 | 57.636 | 57.301 | 56.966 | 56.631 | 56.296 | 55.961 |
| 55.940 | 55.617 | 55.295 | 54.972 | 54.649 | 54.326 | 54.003 | 53.680 | 53.357 |
| 53.946 | 53.631 | 53.317 | 53.002 | 52.688 | 52.373 | 52.058 | 51.744 | 51.429 |
| 52.004 | 51.697 | 51.391 | 51.085 | 50.778 | 50.472 | 50.165 | 49.859 | 49.552 |
| 50.139 | 49.840 | 49.542 | 49.243 | 48.945 | 48.646 | 48.348 | 48.049 | 47.750 |
| 48.114 | 47.825 | 47.535 | 47.246 | 46.956 | 46.666 | 46.377 | 46.087 | 45.798 |
| 46.426 | 46.142 | 45.861 | 45.578 | 45.296 | 45.014 | 44.731 | 44.449 | 44.166 |
| 44.757 | 44.482 | 44.206 | 43.931 | 43.656 | 43.381 | 43.105 | 42.830 | 42.555 |
| 43.697 | 43.425 | 43.153 | 42.882 | 42.610 | 42.338 | 42.066 | 41.795 | 41.523 |
| 42.019 | 41.755 | 41.491 | 41.227 | 40.963 | 40.698 | 40.434 | 40.170 | 39.906 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 41.236
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 55.606 | 55.295 | 54.983 | 54.672 | 54.361 | 54.049 | 53.738 | 53.426 | 53.115 |
| 55.005 | 54.694 | 54.382 | 54.071 | 53.760 | 53.449 | 53.138 | 52.827 | 52.516 |
| 48.324 | 48.048 | 47.772 | 47.496 | 47.220 | 46.944 | 46.668 | 46.391 | 46.115 |
| 45.846 | 45.581 | 45.316 | 45.052 | 44.787 | 44.523 | 44.258 | 43.993 | 43.729 |
| 44.022 | 43.765 | 43.509 | 43.252 | 42.995 | 42.739 | 42.482 | 42.225 | 41.968 |
| 42.254 | 42.005 | 41.756 | 41.507 | 41.258 | 41.009 | 40.760 | 40.511 | 40.262 |

Table VIII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 40.565 | 40.323 | 40.082 | 39.840 | 39.598 | 39.357 | 39.115 | 38.874 | 38.632 |
| 38.731 | 39.498 | 38.265 | 38.032 | 37.798 | 37.565 | 37.332 | 37.099 | 36.866 |
| 37.218 | 36.992 | 36.765 | 36.539 | 36.312 | 36.086 | 35.860 | 35.633 | 35.407 |
| 35.728 | 35.509 | 35.289 | 35.069 | 34.850 | 34.630 | 34.410 | 34.190 | 33.971 |
| 34.307 | 34.591 | 34.375 | 34.158 | 33.942 | 33.725 | 33.509 | 33.292 | 33.076 |
| 33.317 | 33.108 | 32.898 | 32.689 | 32.479 | 32.270 | 32.060 | 31.851 | 31.641 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 33.151
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.12500E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 46.080 | 45.822 | 45.564 | 45.306 | 45.048 | 44.790 | 44.532 | 44.274 | 44.016 |
| 45.575 | 45.318 | 45.060 | 44.802 | 44.544 | 44.286 | 44.029 | 43.771 | 43.513 |
| 39.298 | 39.074 | 38.849 | 38.625 | 38.400 | 38.176 | 37.951 | 37.727 | 37.502 |
| 37.066 | 36.852 | 36.638 | 36.424 | 36.210 | 35.996 | 35.782 | 35.569 | 35.355 |
| 35.429 | 35.222 | 35.016 | 34.809 | 34.602 | 34.396 | 34.189 | 33.982 | 33.776 |
| 33.849 | 33.649 | 33.450 | 33.250 | 33.051 | 32.851 | 32.652 | 32.452 | 32.253 |
| 32.347 | 32.154 | 31.961 | 31.769 | 31.576 | 31.383 | 31.191 | 30.998 | 30.806 |
| 30.718 | 30.533 | 30.348 | 30.163 | 29.979 | 29.794 | 29.609 | 29.424 | 29.239 |
| 29.388 | 29.209 | 29.031 | 28.852 | 28.673 | 28.494 | 28.316 | 28.137 | 27.958 |
| 28.084 | 27.911 | 27.739 | 27.566 | 27.393 | 27.220 | 27.048 | 26.875 | 26.702 |
| 27.297 | 27.128 | 26.958 | 26.788 | 26.618 | 26.449 | 26.279 | 26.109 | 25.940 |
| 26.000 | 25.836 | 25.673 | 25.509 | 25.346 | 25.182 | 25.019 | 24.855 | 24.692 |

Table IX. Shut-Down Process with Water Coolant (P=3500 KPa, Re=3321).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =150.00
AVERAGE TEMPERATURE =168.220
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 189.913 | 188.127 | 196.341 | 184.555 | 182.770 | 180.984 | 179.193 | 177.412 | 175.627 |
| 183.016 | 186.231 | 184.445 | 182.659 | 180.873 | 179.088 | 177.302 | 175.516 | 173.731 |
| 185.324 | 183.546 | 181.768 | 179.990 | 178.212 | 176.434 | 174.656 | 172.878 | 171.100 |
| 183.036 | 181.262 | 179.488 | 177.714 | 175.940 | 174.166 | 172.392 | 170.616 | 168.844 |
| 180.937 | 179.165 | 177.393 | 175.621 | 173.850 | 172.078 | 170.306 | 168.534 | 166.762 |
| 178.841 | 177.071 | 175.302 | 173.532 | 171.762 | 169.993 | 168.223 | 166.453 | 164.683 |
| 176.752 | 174.984 | 173.217 | 171.449 | 169.682 | 167.914 | 166.147 | 164.379 | 162.612 |
| 174.630 | 172.865 | 171.100 | 169.335 | 167.570 | 165.805 | 164.040 | 162.275 | 160.510 |
| 172.559 | 170.796 | 169.033 | 167.270 | 165.507 | 163.744 | 161.982 | 160.219 | 158.456 |
| 170.487 | 168.726 | 166.965 | 165.204 | 163.444 | 161.683 | 159.922 | 158.161 | 156.401 |
| 168.520 | 166.761 | 165.001 | 163.241 | 161.482 | 159.722 | 157.962 | 156.202 | 154.443 |
| 166.433 | 164.651 | 162.924 | 161.166 | 159.409 | 157.652 | 155.894 | 154.137 | 152.379 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =150.00
ENDING TIME =180.00
AVERAGE TEMPERATURE =155.352
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 177.310 | 175.643 | 173.975 | 172.308 | 170.641 | 168.974 | 167.306 | 165.639 | 163.972 |
| 175.531 | 173.864 | 172.197 | 170.530 | 168.863 | 167.196 | 165.529 | 163.862 | 162.194 |
| 172.047 | 170.397 | 168.746 | 167.095 | 165.445 | 163.794 | 162.144 | 160.493 | 158.842 |
| 169.491 | 167.848 | 166.205 | 164.562 | 162.920 | 161.277 | 159.634 | 157.991 | 156.349 |
| 167.291 | 165.653 | 164.014 | 162.376 | 160.738 | 159.100 | 157.461 | 155.823 | 154.185 |
| 165.097 | 163.464 | 161.830 | 160.196 | 158.563 | 156.929 | 155.295 | 153.662 | 152.028 |
| 162.919 | 161.290 | 159.661 | 158.032 | 156.403 | 154.773 | 153.144 | 151.515 | 149.886 |
| 160.674 | 159.050 | 157.426 | 155.802 | 154.178 | 152.554 | 150.930 | 149.306 | 147.683 |

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OF POOR QUALITY

Table IX. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 156.916 | 155.295 | 153.677 | 152.057 | 150.437 | 148.818 | 147.198 | 145.578 |
| [illegible] | 154.779 | 153.164 | 151.549 | 149.934 | 148.318 | 146.703 | 145.088 | 143.473 |
| [illegible] | 152.859 | 151.246 | 149.633 | 148.020 | 146.407 | 144.794 | 143.181 | 141.568 |
| 152.312 | 150.704 | 149.096 | 147.468 | 145.880 | 144.271 | 142.663 | 141.055 | 139.447 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =180.00
ENDING TIME =210.00
AVERAGE TEMPERATURE =141.464
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 163.581 | 162.043 | 160.505 | 158.966 | 157.428 | 155.890 | 154.352 | 152.814 | 151.276 |
| 161.931 | 160.393 | 158.855 | 157.318 | 155.780 | 154.242 | 152.704 | 151.166 | 149.628 |
| 157.621 | 156.108 | 154.596 | 153.084 | 151.572 | 150.060 | 148.547 | 147.035 | 145.523 |
| 154.832 | 153.332 | 151.831 | 150.339 | 148.830 | 147.329 | 145.828 | 144.327 | 142.827 |
| 152.542 | 151.049 | 149.555 | 148.061 | 146.567 | 145.073 | 143.580 | 142.086 | 140.592 |
| 150.264 | 148.777 | 147.290 | 145.803 | 144.316 | 142.829 | 141.342 | 139.855 | 138.368 |
| 148.009 | 146.529 | 145.049 | 143.569 | 142.089 | 140.609 | 139.129 | 137.649 | 136.169 |
| [illegible] | 144.183 | 142.710 | 141.238 | 139.766 | 138.294 | 136.822 | 135.350 | 133.877 |
| [illegible] | 141.997 | 140.531 | 139.066 | 137.600 | 136.134 | 134.669 | 133.203 | 131.737 |
| 141.268 | 139.809 | 138.350 | 136.891 | 135.432 | 133.973 | 132.514 | 131.055 | 129.596 |
| 139.404 | 137.946 | 136.493 | 135.037 | 133.581 | 132.126 | 130.670 | 129.214 | 127.759 |
| 137.183 | 135.734 | 134.286 | 132.837 | 131.389 | 129.940 | 128.492 | 127.043 | 125.595 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =210.00
ENDING TIME =240.00
AVERAGE TEMPERATURE =127.023
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 149.126 | 147.724 | 146.322 | 144.919 | 143.517 | 142.115 | 140.713 | 139.310 | 137.908 |
| 147.613 | 146.211 | 144.809 | 143.407 | 142.005 | 140.603 | 139.201 | 137.799 | 136.397 |
| 142.504 | 141.137 | 139.770 | 138.403 | 137.035 | 135.668 | 134.301 | 132.934 | 131.567 |
| 139.535 | 138.183 | 136.831 | 135.478 | 134.126 | 132.773 | 131.421 | 130.068 | 128.716 |

Table IX. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 137.176 | 135.834 | 134.491 | 133.148 | 131.804 | 130.461 | 129.118 | 127.774 | 126.431 |
| 134.835 | 133.502 | 132.168 | 130.834 | 129.499 | 128.165 | 126.831 | 125.497 | 124.162 |
| 132.529 | 131.204 | 129.879 | 128.553 | 127.228 | 125.903 | 124.578 | 123.252 | 121.927 |
| 130.092 | 128.778 | 127.463 | 126.148 | 124.833 | 123.518 | 122.203 | 120.889 | 119.574 |
| 127.871 | 126.565 | 125.259 | 123.952 | 122.646 | 121.340 | 120.033 | 118.727 | 117.420 |
| 125.643 | 124.351 | 123.053 | 121.756 | 120.458 | 119.160 | 117.853 | 116.565 | 115.267 |
| 123.858 | 122.564 | 121.271 | 119.978 | 118.684 | 117.391 | 116.098 | 114.805 | 113.511 |
| 121.602 | 120.319 | 119.035 | 117.751 | 116.467 | 115.183 | 113.899 | 112.615 | 111.332 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =112.469
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 134.337 | 133.074 | 131.811 | 130.547 | 129.284 | 128.021 | 126.758 | 125.495 | 124.232 |
| 132.966 | 131.702 | 130.439 | 129.176 | 127.913 | 126.650 | 125.387 | 124.125 | 122.862 |
| 127.143 | 125.923 | 124.703 | 123.483 | 122.264 | 121.044 | 119.824 | 118.604 | 117.384 |
| 124.055 | 122.853 | 121.650 | 120.448 | 119.246 | 118.043 | 116.841 | 115.639 | 114.436 |
| 121.561 | 120.469 | 119.278 | 118.087 | 116.895 | 115.704 | 114.512 | 113.321 | 112.130 |
| 119.289 | 118.109 | 116.928 | 115.748 | 114.567 | 113.387 | 112.207 | 111.026 | 109.846 |
| 116.961 | 115.792 | 114.622 | 113.452 | 112.283 | 111.113 | 109.944 | 108.774 | 107.604 |
| 114.481 | 113.324 | 112.166 | 111.009 | 109.852 | 108.695 | 107.538 | 106.381 | 105.224 |
| 112.252 | 111.115 | 109.968 | 108.821 | 107.674 | 106.527 | 105.380 | 104.233 | 103.087 |
| 110.043 | 108.907 | 107.770 | 106.634 | 105.497 | 104.361 | 103.224 | 102.088 | 100.951 |
| 108.342 | 107.211 | 106.079 | 104.948 | 103.817 | 102.686 | 101.554 | 100.423 | 99.292 |
| 106.089 | 104.969 | 103.849 | 102.729 | 101.609 | 100.489 | 99.368 | 98.248 | 97.128 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE = 98.202
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

Table IX. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 118.456 | 117.331 | 116.207 | 115.082 | 113.958 | 112.834 | 111.709 | 110.585 |
| [illegible] | 117.225 | 116.101 | 114.977 | 113.853 | 112.729 | 111.604 | 110.480 | 109.356 |
| 111.945 | 110.871 | 109.797 | 108.723 | 107.645 | 106.575 | 105.501 | 104.427 | 103.353 |
| 108.805 | 107.751 | 106.697 | 105.642 | 104.587 | 103.533 | 102.478 | 101.424 | 100.369 |
| 106.412 | 105.370 | 104.328 | 103.286 | 102.244 | 101.202 | 100.150 | 99.118 | 98.076 |
| 104.048 | 103.018 | 101.989 | 100.959 | 99.930 | 98.900 | 97.871 | 96.841 | 95.811 |
| 101.737 | 100.720 | 99.702 | 98.685 | 97.668 | 96.650 | 95.633 | 94.616 | 93.598 |
| 99.257 | 98.254 | 97.251 | 96.248 | 95.244 | 94.241 | 93.238 | 92.235 | 91.232 |
| 97.076 | 96.084 | 95.093 | 94.101 | 93.109 | 92.117 | 91.126 | 90.134 | 89.142 |
| 94.899 | 93.918 | 92.938 | 91.958 | 90.978 | 89.998 | 89.018 | 88.038 | 87.058 |
| 93.303 | 92.329 | 91.354 | 90.380 | 89.406 | 88.432 | 87.457 | 86.483 | 85.509 |
| 91.092 | 90.130 | 89.168 | 88.207 | 87.245 | 86.283 | 85.321 | 84.359 | 83.398 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =300.00
ENDING TIME =330.00
AVERAGE TEMPERATURE = 84.561
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 105.182 | 104.193 | 103.204 | 102.215 | 101.226 | 100.237 | 99.248 | 98.259 | 97.270 |
| 104.090 | 103.101 | 102.113 | 101.124 | 100.135 | 99.147 | 98.158 | 97.170 | 96.181 |
| 97.268 | 96.334 | 95.401 | 94.468 | 93.535 | 92.602 | 91.669 | 90.735 | 89.802 |
| 94.145 | 93.232 | 92.320 | 91.407 | 90.495 | 89.582 | 88.670 | 87.757 | 86.845 |
| 91.792 | 90.894 | 89.995 | 89.096 | 88.197 | 87.298 | 86.399 | 85.500 | 84.601 |
| 89.476 | 88.591 | 87.705 | 86.820 | 85.935 | 85.049 | 84.164 | 83.278 | 82.393 |
| 87.222 | 86.349 | 85.477 | 84.605 | 83.733 | 82.860 | 81.988 | 81.116 | 80.244 |
| 84.790 | 83.933 | 83.076 | 82.219 | 81.362 | 80.505 | 79.648 | 78.791 | 77.934 |
| 82.683 | 81.838 | 80.994 | 80.149 | 79.304 | 78.460 | 77.615 | 76.770 | 75.925 |
| 80.584 | 79.752 | 78.919 | 78.087 | 77.255 | 76.423 | 75.590 | 74.758 | 73.926 |
| 79.108 | 78.282 | 77.456 | 76.630 | 75.804 | 74.978 | 74.152 | 73.326 | 72.499 |
| 76.979 | 76.166 | 75.353 | 74.540 | 73.728 | 72.915 | 72.102 | 71.289 | 70.476 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =330.00

Table IX. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] 263 | 53.701 | 53.134 | 52.568 | 52.001 | 51.434 | 50.868 | 50.301 | 49.734 |
| [illegible] | 51.855 | 51.301 | 50.748 | 50.195 | 49.643 | 49.088 | 48.534 | 47.981 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 49.692
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 66.638 | 66.011 | 65.385 | 64.758 | 64.131 | 63.505 | 62.878 | 62.252 | 61.625 |
| 65.924 | 65.298 | 64.672 | 64.046 | 63.420 | 62.794 | 62.168 | 61.542 | 60.915 |
| 58.933 | 58.367 | 57.802 | 57.236 | 56.671 | 56.106 | 55.540 | 54.975 | 54.409 |
| 56.217 | 55.673 | 55.128 | 54.583 | 54.038 | 53.493 | 52.948 | 52.403 | 51.858 |
| 54.212 | 53.681 | 53.151 | 52.620 | 52.089 | 51.558 | 51.027 | 50.496 | 49.965 |
| 52.260 | 51.743 | 51.225 | 50.708 | 50.191 | 49.674 | 49.157 | 48.640 | 48.123 |
| 50.385 | 49.881 | 49.377 | 48.873 | 48.369 | 47.866 | 47.362 | 46.858 | 46.354 |
| 48.349 | 47.861 | 47.372 | 46.883 | 46.395 | 45.906 | 45.417 | 44.929 | 44.440 |
| 46.652 | 46.175 | 45.698 | 45.222 | 44.745 | 44.269 | 43.792 | 43.315 | 42.839 |
| 44.974 | 44.509 | 44.045 | 43.580 | 43.116 | 42.652 | 42.187 | 41.723 | 41.258 |
| 43.908 | 43.449 | 42.991 | 42.532 | 42.074 | 41.615 | 41.157 | 40.698 | 40.240 |
| 42.221 | 41.776 | 41.330 | 40.884 | 40.438 | 39.992 | 39.547 | 39.101 | 38.655 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =420.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 40.496
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 55.884 | 55.359 | 54.833 | 54.308 | 53.782 | 53.257 | 52.731 | 52.206 | 51.680 |
| 55.279 | 54.754 | 54.229 | 53.704 | 53.179 | 52.654 | 52.129 | 51.604 | 51.079 |
| 48.564 | 48.098 | 47.632 | 47.166 | 46.701 | 46.235 | 45.769 | 45.303 | 44.837 |
| 46.073 | 45.626 | 45.180 | 44.733 | 44.286 | 43.840 | 43.393 | 42.947 | 42.500 |
| 44.239 | 43.806 | 43.373 | 42.940 | 42.507 | 42.073 | 41.640 | 41.207 | 40.774 |
| 42.462 | 42.042 | 41.622 | 41.201 | 40.781 | 40.361 | 39.941 | 39.521 | 39.101 |

Table IX. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 40.764 | 40.354 | 39.943 | 39.542 | 39.133 | 38.725 | 38.318 | 37.910 | 37.502 |
| 39.920 | 39.527 | 38.133 | 37.740 | 37.347 | 36.953 | 36.560 | 36.167 | 35.773 |
| 37.399 | 37.017 | 36.635 | 36.253 | 35.871 | 35.489 | 35.107 | 34.725 | 34.343 |
| 35.902 | 35.531 | 35.160 | 34.789 | 34.419 | 34.048 | 33.677 | 33.306 | 32.935 |
| 34.976 | 34.610 | 34.245 | 33.880 | 33.515 | 33.149 | 32.784 | 32.419 | 32.054 |
| 33.477 | 33.124 | 32.770 | 32.417 | 32.063 | 31.710 | 31.356 | 31.003 | 30.649 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 32.535
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 46.210 | 45.875 | 45.439 | 45.004 | 44.569 | 44.133 | 43.698 | 43.262 | 42.827 |
| 45.803 | 45.368 | 44.933 | 44.498 | 44.063 | 43.628 | 43.193 | 42.757 | 42.322 |
| 39.494 | 39.115 | 38.735 | 38.357 | 37.978 | 37.599 | 37.220 | 36.841 | 36.462 |
| 37.250 | 36.889 | 36.528 | 36.167 | 35.806 | 35.445 | 35.084 | 34.722 | 34.361 |
| 35.604 | 35.255 | 34.906 | 34.556 | 34.209 | 33.860 | 33.512 | 33.163 | 32.814 |
| 34.015 | 33.679 | 33.342 | 33.005 | 32.669 | 32.332 | 31.996 | 31.659 | 31.323 |
| 32.505 | 32.180 | 31.855 | 31.530 | 31.205 | 30.880 | 30.555 | 30.230 | 29.905 |
| 30.868 | 30.556 | 30.244 | 29.932 | 29.620 | 29.308 | 28.996 | 28.684 | 28.372 |
| 29.531 | 29.230 | 28.928 | 28.626 | 28.325 | 28.023 | 27.721 | 27.419 | 27.118 |
| 28.220 | 27.929 | 27.637 | 27.346 | 27.054 | 26.763 | 26.471 | 26.180 | 25.889 |
| 27.429 | 27.143 | 26.856 | 26.570 | 26.284 | 25.997 | 25.711 | 25.424 | 25.138 |
| 26.125 | 25.849 | 25.573 | 25.297 | 25.021 | 24.745 | 24.470 | 24.194 | 23.918 |

Table X. Shut-Down Process with Water Coolant (P=0 KPa, Re=3321).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =150.00
AVERAGE TEMPERATURE =165.467
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 178.575 | 178.019 | 177.464 | 176.909 | 176.354 | 175.799 | 175.243 | 174.688 | 174.133 |
| 177.005 | 176.450 | 175.895 | 175.340 | 174.785 | 174.230 | 173.674 | 173.119 | 172.564 |
| 174.685 | 174.134 | 173.581 | 173.028 | 172.475 | 171.923 | 171.370 | 170.817 | 170.264 |
| 172.747 | 172.195 | 171.643 | 171.092 | 170.540 | 169.989 | 169.437 | 168.886 | 168.334 |
| 170.985 | 170.434 | 169.883 | 169.332 | 168.781 | 168.230 | 167.679 | 167.128 | 166.578 |
| 169.225 | 168.674 | 168.124 | 167.574 | 167.024 | 166.474 | 165.924 | 165.373 | 164.823 |
| 167.471 | 166.921 | 166.372 | 165.822 | 165.273 | 164.723 | 164.174 | 163.624 | 163.075 |
| 165.685 | 165.137 | 164.588 | 164.039 | 163.490 | 162.942 | 162.393 | 161.844 | 161.295 |
| 163.948 | 163.400 | 162.852 | 162.304 | 161.755 | 161.207 | 160.659 | 160.111 | 159.563 |
| 162.208 | 161.661 | 161.113 | 160.566 | 160.019 | 159.471 | 158.924 | 158.376 | 157.829 |
| 160.569 | 160.022 | 159.475 | 158.928 | 158 381 | 157.834 | 157.287 | 156.739 | 156.192 |
| 158.819 | 158.273 | 157 727 | 157.180 | 156.634 | 156.087 | 155.541 | 154.995 | 154.449 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =150.00
ENDING TIME =180.00
AVERAGE TEMPERATURE =152.804
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 166.724 | 166.206 | 165.687 | 165.169 | 164.651 | 164.132 | 163.614 | 163.096 | 162.577 |
| 165.252 | 164.733 | 164.215 | 163.697 | 163.178 | 162.660 | 162.142 | 161.624 | 161.105 |
| 162.172 | 161.658 | 161.145 | 160.632 | 160.119 | 159.606 | 159.093 | 158.579 | 158.066 |
| 159.963 | 159.452 | 158.941 | 158.430 | 157.920 | 157.409 | 156.898 | 156.387 | 155.877 |
| 158.089 | 157.580 | 157.070 | 156.561 | 156.052 | 155.542 | 155.033 | 154.524 | 154.014 |
| 156.220 | 155.712 | 155.204 | 154.696 | 154.189 | 153.681 | 153.173 | 152.665 | 152.157 |
| 154.365 | 153.859 | 153.352 | 152.845 | 152.339 | 151.832 | 151.326 | 150.819 | 150.313 |
| 152.444 | 151.939 | 151.435 | 150.930 | 150.425 | 149.920 | 149.415 | 148.910 | 148.405 |

Table X: Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 150.624 | 150.121 | 149.617 | 149.113 | 148.610 | 148.106 | 147.603 | 147.099 | 146.596 |
| 148.800 | 148.298 | 147.796 | 147.294 | 146.792 | 146.289 | 145.787 | 145.285 | 144.783 |
| 147.164 | 146.682 | 146.181 | 145.680 | 145.178 | 144.677 | 144.175 | 143.674 | 143.172 |
| 145.340 | 144.840 | 144.340 | 143.840 | 143.340 | 142.840 | 142.340 | 141.840 | 141.340 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =180.00
ENDING TIME =210.00
AVERAGE TEMPERATURE =139.137
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 153.815 | 153.337 | 152.858 | 152.380 | 151.902 | 151.424 | 150.946 | 150.467 | 149.989 |
| 152.448 | 151.970 | 151.492 | 151.014 | 150.536 | 150.057 | 149.579 | 149.101 | 148.623 |
| 148.573 | 148.103 | 147.633 | 147.163 | 146.692 | 146.222 | 145.752 | 145.282 | 144.812 |
| 146.129 | 145.662 | 145.195 | 144.729 | 144.262 | 143.795 | 143.329 | 142.862 | 142.395 |
| 144.152 | 143.687 | 143.223 | 142.759 | 142.294 | 141.830 | 141.365 | 140.901 | 140.436 |
| 142.184 | 141.722 | 141.259 | 140.797 | 140.335 | 139.873 | 139.410 | 138.948 | 138.485 |
| 140.238 | 139.777 | 139.317 | 138.857 | 138.397 | 137.937 | 137.477 | 137.016 | 136.556 |
| 138.194 | 137.736 | 137.279 | 136.821 | 136.363 | 135.906 | 135.448 | 134.990 | 134.533 |
| 136.303 | 135.848 | 135.392 | 134.936 | 134.481 | 134.025 | 133.569 | 133.114 | 132.658 |
| 134.408 | 133.955 | 133.501 | 133.048 | 132.594 | 132.140 | 131.687 | 131.233 | 130.780 |
| 132.826 | 132.374 | 131.921 | 131.469 | 131.016 | 130.564 | 130.111 | 129.658 | 129.206 |
| 130.903 | 130.453 | 130.002 | 129.552 | 129.102 | 128.651 | 128.201 | 127.751 | 127.300 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =210.00
ENDING TIME =240.00
AVERAGE TEMPERATURE =124.926
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 140.223 | 139.787 | 139.351 | 138.915 | 138.479 | 138.043 | 137.607 | 137.171 | 136.735 |
| 138.968 | 138.532 | 138.097 | 137.661 | 137.225 | 136.789 | 136.353 | 135.917 | 135.481 |
| 134.324 | 133.899 | 133.474 | 133.049 | 132.624 | 132.199 | 131.774 | 131.349 | 130.924 |
| 131.691 | 131.271 | 130.850 | 130.430 | 130.010 | 129.589 | 129.169 | 128.748 | 128.328 |

Table X. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 32 | 129.215 | 128.797 | 128.379 | 127.962 | 127.544 | 127.126 | 126.709 | 126.291 |
| 186 | 127.171 | 126.757 | 126.342 | 125.927 | 125.512 | 125.097 | 124.683 | 124.268 |
| 570 | 125.159 | 124.746 | 124.334 | 123.922 | 123.510 | 123.098 | 122.686 | 122.274 |
| 429 | 123.020 | 122.612 | 122.203 | 121.794 | 121.385 | 120.977 | 120.568 | 120.159 |
| 490 | 121.094 | 120.678 | 120.272 | 119.866 | 119.459 | 119.053 | 118.647 | 118.241 |
| 547 | 119.144 | 118.740 | 118.337 | 117.934 | 117.530 | 117.127 | 116.723 | 116.320 |
| 014 | 117.612 | 117.210 | 116.808 | 116.405 | 116.003 | 115.601 | 115.199 | 114.797 |
| 037 | 115.637 | 115.238 | 114.839 | 114.440 | 114.041 | 113.641 | 113.242 | 112.843 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =110.606
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5.317 | 125.924 | 125.531 | 125.139 | 124.746 | 124.353 | 123.961 | 123.568 | 123.175 |
| 5.178 | 124.785 | 124.392 | 124.000 | 123.607 | 123.215 | 122.822 | 122.429 | 122.037 |
| 9.845 | 119.465 | 119.086 | 118.707 | 118.328 | 117.948 | 117.569 | 117.190 | 116.811 |
| 7.081 | 116.707 | 116.334 | 115.960 | 115.586 | 115.212 | 114.838 | 114.465 | 114.091 |
| 4.969 | 114.599 | 114.228 | 113.858 | 113.487 | 113.117 | 112.746 | 112.376 | 112.006 |
| 2.875 | 112.508 | 112.141 | 111.774 | 111.407 | 111.040 | 110.672 | 110.306 | 109.939 |
| 10.820 | 110.456 | 110.093 | 109.729 | 109.365 | 109.002 | 108.638 | 108.274 | 107.911 |
| 08.617 | 108.257 | 107.897 | 107.538 | 107.178 | 106.818 | 106.459 | 106.099 | 105.739 |
| 06.659 | 106.303 | 105.946 | 105.590 | 105.233 | 104.877 | 104.520 | 104.163 | 103.807 |
| 04.700 | 104.346 | 103.993 | 103.640 | 103.286 | 102.933 | 102.580 | 102.226 | 101.873 |
| 03.230 | 102.878 | 102.527 | 102.175 | 101.823 | 101.472 | 101.120 | 100.769 | 100.418 |
| 101.233 | 100.885 | 100.536 | 100.188 | 99.840 | 99.492 | 99.143 | 98.795 | 98.447 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE = 96.569
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

Table X. Continued.

ENDING TIME =360.00
AVERAGE TEMPERATURE = 70.606
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 85.963 | 85.696 | 85.429 | 85.162 | 84.894 | 84.627 | 84.360 | 84.093 | 83.825 |
| 85.165 | 84.898 | 84.631 | 84.364 | 84.097 | 83.829 | 83.562 | 83.295 | 83.028 |
| 78.615 | 78.367 | 78.118 | 77.869 | 77.620 | 77.372 | 77.123 | 76.874 | 76.625 |
| 75.844 | 75.602 | 75.359 | 75.117 | 74.875 | 74.632 | 74.391 | 74.149 | 73.907 |
| 73.795 | 73.557 | 73.319 | 73.082 | 72.844 | 72.606 | 72.368 | 72.131 | 71.893 |
| 71.782 | 71.549 | 71.316 | 71.082 | 70.849 | 70.615 | 70.382 | 70.149 | 69.915 |
| 69.831 | 69.602 | 69.373 | 69.144 | 68.915 | 68.686 | 68.457 | 68.227 | 67.998 |
| 67.708 | 67.484 | 67.260 | 67.035 | 66.812 | 66.587 | 66.363 | 66.138 | 65.914 |
| 65.904 | 65.684 | 65.463 | 65.243 | 65.023 | 64.802 | 64.582 | 64.362 | 64.141 |
| 64.108 | 63.891 | 63.675 | 63.459 | 63.242 | 63.026 | 62.810 | 62.593 | 62.377 |
| 62.918 | 62.704 | 62.490 | 62.275 | 62.061 | 61.847 | 61.632 | 61.418 | 61.203 |
| 61.093 | 60.883 | 60.673 | 60.463 | 60.253 | 60.042 | 59.832 | 59.622 | 59.412 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =360.00
ENDING TIME =390.00
AVERAGE TEMPERATURE = 59.133
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 73.831 | 73.602 | 73.372 | 73.142 | 72.913 | 72.683 | 72.454 | 72.224 | 71.995 |
| 73.138 | 72.908 | 72.679 | 72.449 | 72.220 | 71.991 | 71.761 | 71.532 | 71.302 |
| 66.523 | 66.312 | 66.102 | 65.891 | 65.681 | 65.470 | 65.260 | 65.049 | 64.839 |
| 63.867 | 63.663 | 63.459 | 63.256 | 63.052 | 62.848 | 62.644 | 62.440 | 62.236 |
| 61.914 | 61.715 | 61.515 | 61.316 | 61.116 | 60.917 | 60.717 | 60.518 | 60.318 |
| 60.003 | 59.806 | 59.613 | 59.417 | 59.222 | 59.027 | 58.832 | 58.637 | 58.442 |
| 58.158 | 57.967 | 57.776 | 57.585 | 57.395 | 57.204 | 57.013 | 56.822 | 56.631 |
| 56.146 | 55.961 | 55.775 | 55.589 | 55.403 | 55.217 | 55.031 | 54.845 | 54.659 |
| 54.458 | 54.276 | 54.094 | 53.912 | 53.730 | 53.548 | 53.366 | 53.184 | 53.002 |
| 52.781 | 52.603 | 52.425 | 52.247 | 52.069 | 51.891 | 51.713 | 51.535 | 51.356 |

Table X. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible].707 | 51.531 | 51.355 | 51.179 | 51.003 | 50.826 | 50.650 | 50.474 | 50.298 |
| [illegible].009 | 49.837 | 49.665 | 49.493 | 49.321 | 49.149 | 48.977 | 48.805 | 48.633 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 48.849
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 62.659 | 62.465 | 62.270 | 62.075 | 61.880 | 61.685 | 61.491 | 61.296 | 61.101 |
| 62.064 | 61.869 | 61.674 | 61.480 | 61.285 | 61.090 | 60.896 | 60.701 | 60.506 |
| 55.550 | 55.374 | 55.198 | 55.022 | 54.847 | 54.671 | 54.495 | 54.319 | 54.143 |
| 53.057 | 52.868 | 52.718 | 52.549 | 52.380 | 52.210 | 52.041 | 51.871 | 51.702 |
| 51.230 | 51.065 | 50.900 | 50.735 | 50.570 | 50.405 | 50.240 | 50.075 | 49.910 |
| 49.450 | 49.289 | 49.128 | 48.967 | 48.807 | 48.646 | 48.485 | 48.324 | 48.164 |
| 47.739 | 47.583 | 47.426 | 47.269 | 47.113 | 46.956 | 46.799 | 46.643 | 46.486 |
| 45.873 | 45.721 | 45.569 | 45.417 | 45.265 | 45.113 | 44.961 | 44.809 | 44.657 |
| 44.324 | 44.175 | 44.027 | 43.879 | 43.731 | 43.583 | 43.435 | 43.286 | 43.138 |
| 42.790 | 42.646 | 42.501 | 42.357 | 42.212 | 42.068 | 41.924 | 41.779 | 41.635 |
| 41.836 | 41.693 | 41.551 | 41.408 | 41.266 | 41.123 | 40.981 | 40.838 | 40.695 |
| 40.289 | 40.150 | 40.011 | 39.873 | 39.734 | 39.596 | 39.457 | 39.318 | 39.180 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =420.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 39.804
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 52.548 | 52.384 | 52.221 | 52.058 | 51.894 | 51.731 | 51.568 | 51.404 | 51.241 |
| 52.042 | 51.879 | 51.715 | 51.552 | 51.389 | 51.225 | 51.062 | 50.899 | 50.736 |
| 45.777 | 45.632 | 45.487 | 45.342 | 45.197 | 45.052 | 44.907 | 44.763 | 44.618 |
| 43.483 | 43.344 | 43.205 | 43.066 | 42.927 | 42.789 | 42.650 | 42.511 | 42.372 |
| 41.806 | 41.671 | 41.537 | 41.402 | 41.267 | 41.133 | 40.998 | 40.863 | 40.729 |
| 40.179 | 40.048 | 39.918 | 39.787 | 39.656 | 39.526 | 39.395 | 39.264 | 39.134 |

Table X. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 38.496 | 38.370 | 38.243 | 38.126 | 37.999 | 37.863 | 37.736 | [illegible] |
| 36.927 | 36.804 | 36.682 | 36.560 | 36.437 | 36.315 | 36.193 | 36.071 | 35.948 |
| 35.533 | 35.414 | 35.295 | 35.177 | 35.058 | 34.939 | 34.820 | 34.701 | 34.582 |
| 34.159 | 34.043 | 33.928 | 33.813 | 33.697 | 33.582 | 33.467 | 33.351 | [illegible] |
| 33.325 | 33.212 | 33.098 | 32.985 | 32.871 | 32.758 | 32.644 | 32.530 | [illegible] |
| 31.945 | 31.835 | 31.725 | 31.615 | 31.505 | 31.395 | 31.285 | 31.176 | [illegible] |

ELECTROOE TEMPERATURE DISTRIBUTION
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 31.995
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.33210E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 43.546 | 43.410 | 43.275 | 43.139 | 43.004 | 42.869 | 42.733 | 42.598 | 42.463 |
| 43.120 | 42.985 | 42.850 | 42.714 | 42.579 | 42.444 | 42.309 | 42.174 | 42.038 |
| 37.227 | 37.109 | 36.991 | 36.873 | 36.755 | 36.638 | 36.520 | 36.402 | 36.284 |
| 35.156 | 35.043 | 34.931 | 34.819 | 34.707 | 34.594 | 34.482 | 34.370 | 34.258 |
| 33.645 | 33.537 | 33.429 | 33.320 | 33.212 | 33.103 | 32.995 | 32.887 | 32.779 |
| 32.186 | 32.082 | 31.977 | 31.872 | 31.768 | 31.663 | 31.558 | 31.454 | 31.349 |
| 30.798 | 30.697 | 30.596 | 30.495 | 30.394 | 30.293 | 30.192 | 30.091 | 29.990 |
| 29.287 | 29.190 | 29.093 | 28.996 | 28.899 | 28.802 | 28.705 | 28.608 | 28.512 |
| 28.058 | 27.964 | 27.870 | 27.776 | 27.682 | 27.589 | 27.495 | 27.401 | 27.307 |
| 26.850 | 26.759 | 26.669 | 26.578 | 26.487 | 26.397 | 26.306 | 26.216 | 26.125 |
| 26.135 | 25.046 | 25.957 | 25.868 | 25.779 | 25.690 | 25.601 | 25.512 | 25.423 |
| 24.929 | 24.843 | 24.757 | 24.671 | 24.586 | 24.500 | 24.414 | 24.328 | 24.243 |

Table XI. Shut-Down Process with Water Coolant (P=3500 KPa, Re=6167).

```
ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =150.00
AVERAGE TEMPERATURE =155.638
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 169.126 | 168.505 | 167.885 | 167.264 | 166.643 | 166.022 | 165.402 | 164.781 | 164.160 |
| 167.538 | 166.917 | 166.296 | 165.675 | 165.055 | 164.434 | 163.813 | 163.192 | 162.572 |
| 165.240 | 164.622 | 164.003 | 163.385 | 162.767 | 162.149 | 161.531 | 160.913 | 160.295 |
| 163.301 | 162.684 | 162.068 | 161.451 | 160.834 | 160.218 | 159.601 | 158.984 | 158.367 |
| 161.531 | 160.915 | 160.299 | 159.683 | 159.067 | 158.451 | 157.835 | 157.219 | 156.603 |
| 159.763 | 159.149 | 158.533 | 157.917 | 157.302 | 156.687 | 156.072 | 155.457 | 154.842 |
| 158.001 | 157.387 | 156.772 | 156.158 | 155.543 | 154.929 | 154.315 | 153.700 | 153.086 |
| 156.210 | 155.596 | 154.982 | 154.369 | 153.755 | 153.142 | 152.528 | 151.915 | 151.302 |
| 154.464 | 153.851 | 153.238 | 152.625 | 152.012 | 151.400 | 150.787 | 150.174 | 149.561 |
| 152.716 | 152.104 | 151.492 | 150.880 | 150.268 | 149.656 | 149.044 | 148.432 | 147.819 |
| 151.063 | 150.451 | 149.840 | 149.228 | 148.616 | 148.005 | 147.393 | 146.781 | 146.169 |
| 149.306 | 148.695 | 148.085 | 147.474 | 146.863 | 146.252 | 145.641 | 145.030 | 144.419 |

```
ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =150.00
ENDING TIME =180.00
AVERAGE TEMPERATURE =143.729
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 157.903 | 157.323 | 156.744 | 156.164 | 155.584 | 155.005 | 154.425 | 153.846 | 153.266 |
| 156.413 | 155.833 | 155.253 | 154.674 | 154.094 | 153.515 | 152.935 | 152.356 | 151.776 |
| 153.402 | 152.828 | 152.254 | 151.680 | 151.106 | 150.533 | 149.959 | 149.385 | 148.811 |
| 151.216 | 150.645 | 150.074 | 149.503 | 148.932 | 148.361 | 147.790 | 147.219 | 146.648 |
| 149.349 | 148.779 | 148.209 | 147.640 | 147.070 | 146.501 | 145.931 | 145.362 | 144.792 |
| 147.486 | 146.918 | 146.350 | 145.782 | 145.214 | 144.646 | 144.078 | 143.510 | 142.942 |
| 145.636 | 145.070 | 144.503 | 143.937 | 143.371 | 142.804 | 142.238 | 141.672 | 141.105 |
| 143.726 | 143.161 | 142.597 | 142.032 | 141.468 | 140.903 | 140.339 | 139.774 | 139.210 |

Table XI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1.911 | 141.348 | 140.785 | 140.222 | 139.659 | 139.096 | 138.533 | 137.970 | 137.407 |
| 0.093 | 139.531 | 138.970 | 138.408 | 137.847 | 137.285 | 136.724 | 136.162 | 135.601 |
| 3.470 | 137.910 | 137.349 | 136.788 | 136.228 | 135.667 | 135.106 | 134.545 | 133.985 |
| 36.634 | 136.075 | 135.516 | 134.957 | 134.398 | 133.839 | 133.280 | 132.721 | 132.162 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =160.00
ENDING TIME =210.00
AVERAGE TEMPERATURE =130.877
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 45.677 | 145.142 | 144.607 | 144.072 | 143.538 | 143.003 | 142.468 | 141.934 | 141.399 |
| 44.294 | 143.759 | 143.225 | 142.690 | 142.155 | 141.621 | 141.086 | 140.552 | 140.017 |
| 40.538 | 140.013 | 139.487 | 138.961 | 138.436 | 137.910 | 137.384 | 136.859 | 136.333 |
| 38.159 | 137.616 | 137.095 | 136.573 | 136.051 | 135.530 | 135.008 | 134.486 | 133.965 |
| 36.182 | 135.662 | 135.143 | 134.624 | 134.105 | 133.585 | 133.066 | 132.547 | 132.027 |
| 34.234 | 133.717 | 133.200 | 132.634 | 132.167 | 131.650 | 131.133 | 130.616 | 130.099 |
| 32.308 | 131.793 | 131.279 | 130.764 | 130.250 | 129.735 | 129.221 | 128.706 | 128.192 |
| 30.291 | 129.779 | 129.267 | 128.755 | 128.244 | 127.732 | 127.220 | 126.708 | 126.197 |
| 28.418 | 127.909 | 127.399 | 126.890 | 126.380 | 125.871 | 125.361 | 124.852 | 124.342 |
| 26.543 | 126.036 | 125.529 | 125.021 | 124.514 | 124.007 | 123.500 | 122.993 | 122.485 |
| 24.963 | 124.457 | 123.951 | 123.445 | 122.939 | 122.433 | 121.927 | 121.421 | 120.915 |
| 23.062 | 122.559 | 122.055 | 121.552 | 121.048 | 120.544 | 120.041 | 119.537 | 119.034 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =210.00
ENDING TIME =240.00
AVERAGE TEMPERATURE =117.512
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 32.804 | 132.316 | 131.829 | 131.341 | 130.854 | 130.367 | 129.879 | 129.392 | 128.904 |
| 31.535 | 131.048 | 130.560 | 130.073 | 129.586 | 129.098 | 128.611 | 128.124 | 127.636 |
| 27.060 | 126.585 | 126.110 | 125.634 | 125.159 | 124.684 | 124.209 | 123.733 | 123.258 |
| 24.491 | 124.021 | 123.550 | 123.080 | 122.610 | 122.140 | 121.670 | 121.200 | 120.730 |

Table XI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 122.465 | 121.998 | 121.531 | 121.034 | 120.557 | 120.130 | 119.663 | 119.196 | 118.729 |
| 120.453 | 119.989 | 119.525 | 119.061 | 118.597 | 118.134 | 117.670 | 117.206 | 116.742 |
| 118.470 | 118.009 | 117.549 | 117.088 | 116.627 | 116.167 | 115.706 | 115.245 | 114.784 |
| 116.370 | 115.913 | 115.456 | 114.999 | 114.542 | 114.085 | 113.628 | 113.171 | 112.714 |
| 114.462 | 114.008 | 113.554 | 113.100 | 112.646 | 112.192 | 111.737 | 111.283 | 110.829 |
| 112.552 | 112.100 | 111.649 | 111.198 | 110.747 | 110.296 | 109.845 | 109.394 | 108.942 |
| 111.027 | 110.578 | 110.128 | 109.678 | 109.229 | 108.779 | 108.330 | 107.880 | 107.431 |
| 109.086 | 108.640 | 108.193 | 107.747 | 107.301 | 106.854 | 106.408 | 105.962 | 105.516 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =104.044
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 119.633 | 119.194 | 118.755 | 118.316 | 117.877 | 117.439 | 116.999 | 116.560 | 116.121 |
| 118.482 | 118.043 | 117.604 | 117.165 | 116.726 | 116.287 | 115.848 | 115.409 | 114.970 |
| 113.364 | 112.940 | 112.516 | 112.091 | 111.667 | 111.243 | 110.819 | 110.395 | 109.971 |
| 110.679 | 110.261 | 109.843 | 109.426 | 109.008 | 108.590 | 108.172 | 107.754 | 107.336 |
| 108.612 | 108.198 | 107.784 | 107.370 | 106.955 | 106.541 | 106.127 | 105.713 | 105.299 |
| 106.564 | 106.154 | 105.743 | 105.333 | 104.923 | 104.512 | 104.102 | 103.692 | 103.282 |
| 104.554 | 104.147 | 103.740 | 103.334 | 102.927 | 102.521 | 102.114 | 101.707 | 101.301 |
| 102.405 | 102.003 | 101.601 | 101.198 | 100.796 | 100.394 | 99.992 | 99.590 | 99.187 |
| 100.489 | 100.091 | 99.692 | 99.293 | 98.895 | 98.496 | 98.097 | 97.699 | 97.300 |
| 98.573 | 98.178 | 97.783 | 97.388 | 96.992 | 96.597 | 96.202 | 95.807 | 95.412 |
| 97.119 | 96.725 | 96.332 | 95.939 | 95.546 | 95.152 | 94.759 | 94.366 | 93.973 |
| 95.169 | 94.780 | 94.390 | 94.001 | 93.612 | 93.222 | 92.833 | 92.444 | 92.054 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE = 90.842
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

Table XI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 106.492 | 106.101 | 105.710 | 105.319 | 104.928 | 104.537 | 104.146 | 103.756 | 103.365 |
| 105.458 | 105.067 | 104.677 | 104.286 | 103.895 | 103.504 | 103.114 | 102.723 | 102.332 |
| 99.813 | 99.440 | 99.066 | 98.693 | 98.320 | 97.946 | 97.573 | 97.200 | 96.826 |
| 97.074 | 96.708 | 96.341 | 95.974 | 95.608 | 95.241 | 94.875 | 94.508 | 94.142 |
| 94.999 | 94.637 | 94.275 | 93.912 | 93.550 | 93.188 | 92.826 | 92.463 | 92.101 |
| 92.949 | 92.591 | 92.233 | 91.875 | 91.517 | 91.159 | 90.801 | 90.443 | 90.085 |
| 90.944 | 90.591 | 90.237 | 89.883 | 89.530 | 89.176 | 88.822 | 88.469 | 88.115 |
| 88.787 | 88.439 | 88.090 | 87.741 | 87.392 | 87.044 | 96.695 | 86.346 | 85.998 |
| 86.896 | 86.551 | 86.207 | 85.862 | 85.517 | 85.172 | 84.828 | 84.483 | 84.138 |
| 85.007 | 84.666 | 84.325 | 83.985 | 83.644 | 83.303 | 82.963 | 62.622 | 82.281 |
| 83.638 | 83.299 | 82.960 | 82.622 | 82.283 | 81.944 | 81.606 | 81.267 | 80.928 |
| 81.716 | 81.381 | 81.047 | 80.713 | 80.378 | 80.044 | 79.710 | 79.375 | 79.041 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =300.00
ENDING TIME =330.00
AVERAGE TEMPERATURE = 78.239
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 9.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 93.670 | 93.326 | 92.982 | 92.638 | 92.295 | 91.951 | 91.607 | 91.263 | 90.919 |
| 92.752 | 92.409 | 92.065 | 91.721 | 91.378 | 91.034 | 90.690 | 90.347 | 90.003 |
| 86.726 | 86.402 | 86.077 | 85.753 | 85.429 | 85.104 | 84.780 | 84.455 | 84.131 |
| 83.994 | 83.677 | 83.350 | 83.042 | 82.725 | 82.408 | 82.091 | 81.774 | 81.456 |
| 81.947 | 81.635 | 81.322 | 81.010 | 80.697 | 80.385 | 80.073 | 79.760 | 79.448 |
| 79.931 | 79.623 | 79.316 | 79.008 | 78.700 | 78.392 | 78.085 | 77.777 | 77.469 |
| 77.969 | 77.666 | 77.362 | 77.059 | 76.756 | 76.453 | 76.150 | 75.846 | 75.543 |
| 75.846 | 75.548 | 75.250 | 74.952 | 74.654 | 74.356 | 74.059 | 73.761 | 73.463 |
| 74.012 | 73.719 | 73.425 | 73.132 | 72.838 | 72.544 | 72.251 | 71.957 | 71.663 |
| 72.184 | 71.895 | 71.606 | 71.316 | 71.027 | 70.738 | 70.448 | 70.159 | 69.870 |
| 70.913 | 70.626 | 70.339 | 70.052 | 69.764 | 69.477 | 69.190 | 68.903 | 68.616 |
| 69.055 | 68.773 | 68.490 | 68.208 | 67.925 | 67.642 | 67.360 | 67.077 | 66.795 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =330.00

Table XI. Continued.

ENDING TIME =360.00
AVERAGE TEMPERATURE = 56.4[illegible]
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 81.415 | 81.116 | 80.817 | 80.519 | 80.220 | 79.921 | 79.622 | 79.323 | 79.024 |
| 80.610 | 80.311 | 80.012 | 79.714 | 79.415 | 79.116 | 78.818 | 78.519 | 78.220 |
| 74.364 | 74.086 | 73.808 | 73.530 | 73.251 | 72.973 | 72.695 | 72.417 | 72.139 |
| 71.697 | 71.426 | 71.155 | 70.884 | 70.614 | 70.343 | 70.072 | 69.801 | 69.531 |
| 69.715 | 69.449 | 69.183 | 68.917 | 68.651 | 68.386 | 68.120 | 67.854 | 67.588 |
| 67.769 | 67.508 | 67.247 | 66.986 | 66.725 | 66.464 | 66.203 | 65.942 | 65.681 |
| 65.883 | 65.627 | 65.370 | 65.114 | 64.858 | 64.602 | 64.346 | 64.089 | 63.833 |
| 63.836 | 63.585 | 63.334 | 63.084 | 62.833 | 62.582 | 62.331 | 62.081 | 61.830 |
| 62.092 | 61.845 | 61.599 | 61.352 | 61.106 | 60.860 | 60.613 | 60.367 | 60.121 |
| 60.356 | 60.114 | 59.872 | 59.630 | 59.389 | 59.147 | 58.905 | 58.663 | 58.421 |
| 59.194 | 58.954 | 58.714 | 58.474 | 58.235 | 57.995 | 57.755 | 57.516 | 57.276 |
| 57.434 | 57.199 | 56.964 | 56.729 | 56.494 | 56.259 | 56.024 | 55.789 | 55.554 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =360.00
ENDING TIME =390.00
AVERAGE TEMPERATURE = 55.632
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 69.925 | 69.668 | 69.411 | 69.155 | 68.898 | 68.641 | 68.385 | 68.128 | 67.872 |
| 69.226 | 68.969 | 68.713 | 68.456 | 68.200 | 67.943 | 67.687 | 67.430 | 67.174 |
| 62.925 | 62.690 | 62.455 | 62.219 | 61.984 | 61.748 | 61.513 | 61.278 | 61.042 |
| 60.375 | 60.147 | 59.919 | 59.691 | 59.463 | 59.235 | 59.007 | 58.779 | 58.551 |
| 58.491 | 58.268 | 58.045 | 57.822 | 57.599 | 57.376 | 57.153 | 56.930 | 56.707 |
| 56.648 | 56.430 | 56.212 | 55.993 | 55.775 | 55.557 | 55.339 | 55.121 | 54.903 |
| 54.869 | 54.656 | 54.443 | 54.229 | 54.016 | 53.803 | 53.589 | 53.376 | 53.163 |
| 52.935 | 52.727 | 52.520 | 52.312 | 52.104 | 51.896 | 51.688 | 51.480 | 51.272 |
| 51.308 | 51.104 | 50.901 | 50.697 | 50.493 | 50.290 | 50.086 | 49.883 | 49.679 |
| 49.693 | 49.494 | 49.294 | 49.095 | 48.896 | 48.697 | 48.498 | 48.299 | 48.099 |

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OF POOR QUALITY

Table XI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 48.646 | 48.449 | 48.252 | 48.055 | 47.858 | 47.661 | 47.464 | 47.267 | 47.070 |
| 47.013 | 46.821 | 46.629 | 46.436 | 46.244 | 46.052 | 45.859 | 45.667 | 45.475 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 45.958
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 59.344 | 59.126 | 58.909 | 58.691 | 58.473 | 58.255 | 58.037 | 57.819 | 57.602 |
| 58.744 | 58.526 | 58.309 | 58.091 | 57.873 | 57.656 | 57.438 | 57.220 | 57.002 |
| 52.546 | 52.349 | 52.153 | 51.956 | 51.760 | 51.563 | 51.366 | 51.170 | 50.973 |
| 50.156 | 49.967 | 49.777 | 49.588 | 49.398 | 49.209 | 49.020 | 48.830 | 48.641 |
| 48.395 | 48.213 | 48.029 | 47.844 | 47.660 | 47.475 | 47.291 | 47.106 | 46.921 |
| 46.665 | 46.505 | 46.325 | 46.146 | 45.966 | 45.786 | 45.606 | 45.427 | 45.247 |
| 45.040 | 44.865 | 44.689 | 44.514 | 44.339 | 44.164 | 43.989 | 43.814 | 43.639 |
| 43.249 | 43.079 | 42.910 | 42.740 | 42.570 | 42.400 | 42.230 | 42.060 | 41.890 |
| 41.760 | 41.594 | 41.426 | 41.262 | 41.097 | 40.931 | 40.765 | 40.600 | 40.434 |
| 40.286 | 40.125 | 39.963 | 39.802 | 39.640 | 39.479 | 39.317 | 39.156 | 38.994 |
| 39.359 | 39.200 | 39.040 | 38.881 | 38.722 | 38.562 | 38.403 | 38.244 | 38.084 |
| 37.875 | 37.720 | 37.566 | 37.411 | 37.256 | 37.101 | 36.946 | 36.791 | 36.636 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =420.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 37.450
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 49.768 | 49.585 | 49.402 | 49.220 | 49.037 | 48.854 | 48.672 | 48.489 | 48.306 |
| 49.258 | 49.075 | 48.893 | 48.710 | 48.528 | 48.345 | 48.163 | 47.980 | 47.798 |
| 43.301 | 43.139 | 42.977 | 42.815 | 42.653 | 42.491 | 42.329 | 42.167 | 42.005 |
| 41.105 | 40.950 | 40.795 | 40.639 | 40.484 | 40.329 | 40.174 | 40.018 | 39.863 |
| 39.495 | 39.344 | 39.193 | 39.043 | 38.892 | 38.742 | 38.591 | 38.440 | 38.290 |
| 37.932 | 37.786 | 37.640 | 37.494 | 37.348 | 37.202 | 37.056 | 36.910 | 36.764 |

Table XI. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 36.439 | 36.297 | 36.156 | 36.014 | 35.872 | 35.731 | 35.589 | 35.447 | 35.305 |
| 34.815 | 34.678 | 34.541 | 34.405 | 34.268 | 34.131 | 33.994 | 33.858 | 33.721 |
| 33.477 | 33.345 | 33.212 | 33.079 | 32.946 | 32.813 | 32.681 | 32.548 | 32.415 |
| 32.159 | 32.031 | 31.902 | 31.773 | 31.644 | 31.515 | 31.386 | 31.257 | 31.128 |
| 31.352 | 31.225 | 31.098 | 30.972 | 30.845 | 30.718 | 30.591 | 30.464 | 30.337 |
| 30.031 | 29.908 | 29.786 | 29.663 | 29.540 | 29.417 | 29.294 | 29.171 | 29.049 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 30.105
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 41.242 | 41.090 | 40.939 | 40.787 | 40.636 | 40.485 | 40.333 | 40.182 | 40.031 |
| 40.814 | 40.662 | 40.511 | 40.360 | 40.209 | 40.058 | 39.906 | 39.755 | 39.604 |
| 35.213 | 35.082 | 34.950 | 34.818 | 34.687 | 34.555 | 34.423 | 34.292 | 34.160 |
| 33.233 | 33.108 | 32.982 | 32.857 | 32.731 | 32.606 | 32.480 | 32.355 | 32.229 |
| 31.785 | 31.664 | 31.543 | 31.422 | 31.300 | 31.179 | 31.058 | 30.937 | 30.816 |
| 30.387 | 30.270 | 30.153 | 30.036 | 29.919 | 29.802 | 29.685 | 29.568 | 29.451 |
| 29.057 | 28.944 | 28.831 | 28.718 | 28.605 | 28.492 | 28.379 | 28.266 | 28.153 |
| 27.612 | 27.504 | 27.395 | 27.287 | 27.178 | 27.070 | 26.961 | 26.853 | 26.744 |
| 26.434 | 26.330 | 26.225 | 26.120 | 26.015 | 25.910 | 25.805 | 25.700 | 25.595 |
| 25.279 | 25.177 | 25.076 | 24.975 | 24.873 | 24.772 | 24.671 | 24.569 | 24.468 |
| 24.588 | 24.488 | 24.389 | 24.289 | 24.190 | 24.090 | 23.990 | 23.891 | 23.791 |
| 23.435 | 23.340 | 23.244 | 23.148 | 23.052 | 22.956 | 22.860 | 22.764 | 22.668 |

Table XII. Shut-Down Process with Water Coolant (P=0 KPa, Re=6167).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =150.00
AVERAGE TEMPERATURE =151.337
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 165.347 | 164.709 | 164.071 | 163.434 | 162.796 | 162.150 | 161.520 | 160.882 | 160.245 |
| 163.673 | 163.036 | 162.398 | 161.760 | 161.122 | 160.485 | 159.847 | 159.209 | 158.571 |
| 161.307 | 160.672 | 160.037 | 159.402 | 158.767 | 158.132 | 157.497 | 156.862 | 156.227 |
| 159.293 | 158.659 | 158.026 | 157.392 | 156.759 | 156.125 | 155.491 | 154.858 | 154.224 |
| 157.443 | 156.811 | 156.178 | 155.545 | 154.912 | 154.279 | 153.647 | 153.014 | 152.381 |
| 155.596 | 154.964 | 154.332 | 153.700 | 153.068 | 152.436 | 151.804 | 151.172 | 150.540 |
| 153.755 | 153.124 | 152.493 | 151.862 | 151.230 | 150.599 | 149.968 | 149.337 | 148.705 |
| 151.886 | 151.255 | 150.625 | 149.995 | 149.364 | 148.734 | 148.104 | 147.473 | 146.843 |
| 150.061 | 149.431 | 148.802 | 148.172 | 147.543 | 146.913 | 146.283 | 145.654 | 145.024 |
| 148.235 | 147.606 | 146.977 | 146.348 | 145.720 | 145.091 | 144.462 | 143.833 | 143.204 |
| 146.501 | 145.872 | 145.244 | 144.616 | 143.987 | 143.359 | 142.730 | 142.102 | 141.473 |
| 144.667 | 144.039 | 143.411 | 142.784 | 142.156 | 141.528 | 140.901 | 140.273 | 139.645 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =150.00
ENDING TIME =180.00
AVERAGE TEMPERATURE =139.760
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 154.374 | 153.779 | 153.183 | 152.588 | 151.992 | 151.397 | 150.802 | 150.206 | 149.611 |
| 152.805 | 152.209 | 151.614 | 151.019 | 150.423 | 149.828 | 149.232 | 148.637 | 148.042 |
| 149.751 | 149.161 | 148.572 | 147.982 | 147.393 | 146.803 | 146.214 | 145.624 | 145.035 |
| 147.505 | 146.918 | 146.331 | 145.744 | 145.158 | 144.571 | 143.984 | 143.398 | 142.811 |
| 145.569 | 144.984 | 144.399 | 143.814 | 143.229 | 142.644 | 142.058 | 141.473 | 140.888 |
| 143.639 | 143.056 | 142.472 | 141.889 | 141.305 | 140.722 | 140.138 | 139.555 | 138.971 |
| 141.723 | 141.141 | 140.559 | 139.977 | 139.395 | 138.813 | 138.231 | 137.650 | 137.068 |
| 139.748 | 139.168 | 138.588 | 138.008 | 137.428 | 136.848 | 136.268 | 135.688 | 135.109 |

Table XII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible].365 | 118.886 | 118.406 | 117.927 | 117.447 | 116.967 | 116.487 | 116.008 | [illegible] |
| 117.311 | 116.835 | 116.359 | 115.882 | 115.405 | 114.929 | 114.452 | 113.976 | 113.499 |
| 115.286 | 114.813 | 114.340 | 113.867 | 113.393 | 112.920 | 112.447 | 111.973 | 111.500 |
| 113.149 | 112.680 | 112.210 | 111.740 | 111.271 | 110.801 | 110.332 | 109.862 | 109.392 |
| 111.200 | 110.733 | 110.267 | 109.800 | 109.333 | 108.867 | 108.400 | 107.934 | 107.467 |
| 109.249 | 108.786 | 108.322 | 107.859 | 107.395 | 106.932 | 106.468 | 106.005 | 105.541 |
| 107.674 | 107.212 | 106.750 | 106.288 | 105.827 | 105.365 | 104.903 | 104.441 | 103.979 |
| 105.696 | 105.238 | 104.779 | 104.321 | 103.862 | 103.403 | 102.945 | 102.486 | 102.026 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =101.179
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 116.960 | 116.509 | 116.058 | 115.607 | 115.155 | 114.704 | 114.253 | 113.802 | 113.351 |
| 115.749 | 115.298 | 114.847 | 114.396 | 113.945 | 113.494 | 113.043 | 112.592 | 112.141 |
| 110.666 | 110.230 | 109.795 | 109.359 | 108.923 | 108.488 | 108.052 | 107.616 | 107.181 |
| 107.963 | 107.534 | 107.104 | 106.675 | 106.245 | 105.816 | 105.386 | 104.957 | 104.528 |
| 105.864 | 105.438 | 105.013 | 104.587 | 104.162 | 103.736 | 103.311 | 102.885 | 102.460 |
| 103.785 | 103.363 | 102.941 | 102.520 | 102.098 | 101.677 | 101.255 | 100.834 | 100.412 |
| 101.744 | 101.326 | 100.909 | 100.491 | 100.073 | 99.655 | 99.238 | 98.820 | 98.402 |
| 99.571 | 99.157 | 98.744 | 98.331 | 97.918 | 97.504 | 97.091 | 96.678 | 96.265 |
| 97.625 | 97.216 | 96.806 | 96.396 | 95.987 | 95.577 | 95.168 | 94.758 | 94.348 |
| 95.680 | 95.274 | 94.369 | 94.463 | 94.057 | 93.651 | 93.245 | 92.839 | 92.433 |
| 94.186 | 93.782 | 93.378 | 92.974 | 92.570 | 92.166 | 91.762 | 91.357 | 90.953 |
| 92.212 | 91.812 | 91.412 | 91.012 | 90.612 | 90.212 | 89.811 | 89.411 | 89.011 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE = 88.344
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

Table XII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 103.710 | 103.309 | 102.907 | 102.506 | 102.104 | 101.702 | 101.301 | 100.899 |
| [illegible] | 102.624 | 102.223 | 101.821 | 101.420 | 101.019 | 100.617 | 100.216 | 99.814 |
| 97.438 | 97.054 | 96.671 | 96.287 | 95.903 | 95.520 | 95.136 | 94.753 | 94.369 |
| 94.692 | 94.315 | 93.938 | 93.562 | 93.185 | 92.809 | 92.432 | 92.055 | 91.679 |
| 92.595 | 92.223 | 91.851 | 91.479 | 91.107 | 90.734 | 90.362 | 89.990 | 89.618 |
| 90.525 | 90.157 | 89.789 | 89.421 | 89.054 | 88.686 | 88.318 | 87.951 | 87.583 |
| 88.501 | 88.137 | 87.774 | 87.411 | 87.047 | 86.684 | 86.320 | 85.957 | 85.594 |
| 86.330 | 85.972 | 85.613 | 85.255 | 84.897 | 84.538 | 84.180 | 83.522 | 83.464 |
| 84.419 | 84.065 | 83.711 | 83.357 | 83.003 | 82.648 | 82.294 | 81.940 | 81.586 |
| 82.512 | 82.162 | 81.812 | 81.462 | 81.112 | 80.762 | 80.412 | 80.062 | 79.712 |
| 81.112 | 80.764 | 90.416 | 80.068 | 79.720 | 79.372 | 79.024 | 78.676 | 78.328 |
| 79.176 | 78.833 | 76.489 | 78.146 | 77.802 | 77.459 | 77.115 | 76.772 | 76.428 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =300.00
ENDING TIME =330.00
AVERAGE TEMPERATURE = 7[illegible].071
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 91.577 | 91.223 | 90.870 | 90.517 | 90.164 | [illegible] | [illegible] | 89.104 | [illegible] |
| 90.613 | 90.260 | 89.907 | 89.554 | 89.201 | 88.848 | 88.495 | 88.142 | 87.789 |
| 84.662 | 81.329 | 83.996 | 83.663 | 83.329 | 82.996 | 82.663 | 82.329 | 81.996 |
| 81.932 | 81.607 | 81.281 | 80.955 | 80.629 | 80.303 | 79.977 | 79.651 | 79.325 |
| 79.874 | 79.553 | 79.232 | 78.911 | 78.590 | 78.268 | 77.947 | 77.626 | 77.305 |
| 77.847 | 77.530 | 77.214 | 76.898 | 76.582 | 76.266 | 75.949 | 75.633 | 75.317 |
| 75.874 | 75.562 | 75.251 | 74.939 | 74.628 | 74.316 | 74.004 | 73.693 | 73.381 |
| 73.747 | 73.441 | 73.134 | 72.828 | 72.522 | 72.216 | 71.910 | 71.604 | 71.298 |
| 71.903 | 71.601 | 71.300 | 70.998 | 70.696 | 70.395 | 70.093 | 69.791 | 69.490 |
| 70.066 | 69.769 | 69.472 | 69.174 | 68.877 | 62.580 | 68.283 | 67.985 | 67.688 |
| 68.771 | 58.476 | 68.181 | 67.886 | 67.591 | 67.296 | 67.001 | 66.706 | 66.411 |
| 66.909 | 56.619 | 66.329 | 66.038 | 65.748 | 65.458 | 65.168 | 64.877 | 64.587 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =330.00

Table XII. Continued.

ENDING TIME =360.00
AVERAGE TEMPERATURE = 6[illegible].601
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 79.596 | 79.289 | 78.982 | 78.575 | 78.368 | 78.061 | 77.754 | 77.447 | 77.140 |
| 76.750 | 78.444 | 78.137 | 77.830 | 77.523 | 77.216 | 76.909 | 76.602 | 76.296 |
| 72.594 | 72.309 | 72.023 | 71.737 | 71.451 | 71.166 | 70.880 | 70.594 | 70.308 |
| 69.937 | 69.659 | 69.381 | 69.103 | 69.824 | 68.546 | 68.268 | 67.990 | 67.712 |
| 67.951 | 67.677 | 67.404 | 67.131 | 66.858 | 66.585 | 66.312 | 66.039 | 65.766 |
| 56.001 | 65.733 | 65.465 | 65.197 | 64.929 | 64.651 | 64.393 | 64.125 | 63.857 |
| 54.112 | 63.849 | 63.586 | 63.323 | 63.059 | 62.796 | 62.533 | 62.270 | 62.007 |
| 62.069 | 61.811 | 61.554 | 61.296 | 61.038 | 60.781 | 60.523 | 60.256 | 60.008 |
| 60.322 | 60.069 | 59.816 | 59.562 | 59.309 | 59.056 | 58.803 | 58.550 | 58.297 |
| 58.555 | 58.337 | 58.088 | 57.840 | 57.591 | 57.342 | 57.094 | 56.845 | 56.597 |
| 57.406 | 57.160 | 56.913 | 56.667 | 56.421 | 56.175 | 55.928 | 55.682 | 55.436 |
| 55.649 | 55.408 | 55.166 | 54.925 | 54.683 | 54.442 | 54.201 | 53.959 | 53.718 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =360.00
ENDING TIME =390.00
AVERAGE TEMPERATURE = 54.108
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 68.362 | 68.098 | 67.835 | 67.571 | 67.307 | 67.044 | 66.780 | 66.516 | 66.253 |
| 67.629 | 67.365 | 67.102 | 66.838 | 66.575 | 66.311 | 66.048 | 65.784 | 65.521 |
| 61.428 | 61.186 | 60.944 | 60.702 | 60.461 | 60.219 | 59.977 | 59.735 | 59.493 |
| 58.893 | 58.659 | 58.425 | 58.191 | 57.956 | 57.722 | 57.488 | 57.254 | 57.019 |
| 57.011 | 56.782 | 56.552 | 56.323 | 56.094 | 55.865 | 55.536 | 55.407 | 55.178 |
| 55.170 | 54.946 | 54.722 | 54.498 | 54.274 | 54.050 | 53.826 | 53.602 | 53.378 |
| 53.395 | 53.176 | 52.957 | 52.737 | 52.518 | 52.299 | 52.080 | 51.860 | 51.641 |
| 51.470 | 51.257 | 51.043 | 50.829 | 50.616 | 50.402 | 50.189 | 49.975 | 49.761 |
| 49.845 | 49.636 | 49.427 | 49.218 | 49.009 | 48.800 | 48.590 | 48.381 | 48.172 |
| 48.235 | 48.030 | 47.825 | 47.621 | 47.416 | 47.211 | 47.007 | 46.802 | 46.598 |

Table XII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | 46.975 | 46.772 | 46.570 | 46.367 | 46.165 | 45.963 | 45.760 | 45.558 |
| 45.552 | 45.355 | 45.157 | 44.960 | 44.762 | 44.564 | 44.367 | 44.169 | 43.971 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 44.701
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 58.018 | 57.794 | 57.570 | 57 347 | 57.123 | 56.899 | 56.675 | 56.452 | 56.228 |
| 57.389 | 57.165 | 56.942 | 56.718 | 55.494 | 56.271 | 56.047 | 55.824 | 55.600 |
| 51.295 | 51.093 | 50.891 | 50.689 | 50.488 | 50.286 | 50.084 | 49.882 | 49.680 |
| 48.925 | 48.730 | 49.536 | 48.341 | 48.147 | 47.952 | 47.757 | 47.563 | 47.368 |
| 47.173 | 46.984 | 46.794 | 46.604 | 46.415 | 46.225 | 46.036 | 45.846 | 45.656 |
| 45 467 | 45.283 | 45.098 | 44.913 | 44.729 | 44.544 | 44.359 | 44.175 | 43.990 |
| 43.829 | 43.649 | 43.470 | 43.290 | 43 110 | 42.930 | 42.750 | 42.570 | 42.390 |
| 42.052 | 41.878 | 41.703 | 41.529 | 41.354 | 41.180 | 41.005 | 40.831 | 40.656 |
| 40.569 | 40.399 | 40.229 | 40.059 | 39.888 | 39.718 | 39.548 | 39.378 | 39.208 |
| 39.134 | 38.938 | 38.772 | 38.606 | 38.440 | 38.275 | 38.109 | 37.943 | 37.777 |
| 38.171 | 38.007 | 37.843 | 37.679 | 37.516 | 37.352 | 37.188 | 37.024 | 36.861 |
| 36.698 | 36.539 | 36.380 | 36.221 | 36.062 | 35.902 | 35.743 | 35.584 | 35.425 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =420.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 36.428
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 48.655 | 48.468 | 48.280 | 48.092 | 47.905 | 47.717 | 47.529 | 47.342 | 47.154 |
| 48.122 | 47.934 | 47.747 | 47.559 | 47.372 | 47.184 | 46.997 | 46.809 | 46.622 |
| 42.271 | 42.104 | 41.938 | 41.771 | 41.605 | 41.439 | 41.272 | 41.106 | 40.939 |
| 40.096 | 39.937 | 39.777 | 39.618 | 39.458 | 39.299 | 39.139 | 38.980 | 38.820 |
| 38.495 | 38.340 | 38.186 | 38.031 | 37.876 | 37.722 | 37.567 | 37.412 | 37.257 |
| 36.943 | 36.793 | 36.643 | 36.493 | 36.343 | 36.193 | 36.043 | 35.893 | 35.743 |

Table XII. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | 35.163 | 35.023 | 34.878 | 34.732 | 34.586 | 34.441 | 34.295 |
| 33.851 | 33.711 | 33.570 | 33.430 | 33.289 | 33.149 | 33.008 | 32.868 | 32.727 |
| 32.523 | 32.367 | 32.250 | 32.114 | 31.977 | 31.841 | 31.704 | 31.568 | 31.432 |
| 31.216 | 31.083 | 30.951 | 30.819 | 30.686 | 30.554 | 30.421 | 30.289 | 30.156 |
| 30.406 | 30.275 | 30.145 | 30.014 | 29.884 | 29.753 | 29.623 | 29.492 | 29.362 |
| 29.098 | 28.972 | 28.846 | 28.719 | 28.593 | 28.467 | 28.341 | 28.214 | 28.088 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 29.285
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.61670E+04
COOLANT:WATER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 40.320 | 40.164 | 40.009 | 39.853 | 39.698 | 39.542 | 39.387 | 39.231 | 39.076 |
| 39.872 | 39.717 | 39.562 | 39.406 | 39.251 | 39.096 | 38.940 | 38.785 | 38.630 |
| 34.375 | 34.240 | 34.105 | 33.970 | 33.834 | 33.699 | 33.564 | 33.428 | 33.293 |
| 32.418 | 32.289 | 32.160 | 32.031 | 31.902 | 31.773 | 31.644 | 31.515 | 31.386 |
| 30.981 | 30.856 | 30.732 | 30.607 | 30.483 | 30.358 | 30.234 | 30.109 | 29.985 |
| 29.594 | 29.474 | 29.354 | 29.234 | 29.113 | 28.993 | 28.873 | 28.753 | 28.632 |
| 28.276 | 28.160 | 28.044 | 27.928 | 27.812 | 27.696 | 27.579 | 27.463 | 27.347 |
| 26.848 | 26.736 | 26.625 | 26.513 | 26.402 | 26.291 | 26.179 | 26.068 | 25.956 |
| 25.681 | 25.573 | 25.466 | 25.358 | 25.250 | 25.142 | 25.035 | 24.927 | 24.819 |
| 24.537 | 24.433 | 24.329 | 24.225 | 24.121 | 24.016 | 23.912 | 23.808 | 23.704 |
| 23.845 | 23.743 | 23.641 | 23.538 | 23.436 | 23.334 | 23.231 | 23.129 | 23.027 |
| 22.707 | 22.609 | 22.510 | 22.412 | 22.313 | 22.215 | 22.116 | 22.018 | 21.919 |

## Chapter VI

## CURRENT DENSITY DISTRIBUTION

In this chapter, the modified computer code was employed to simulate the current density distribution during the considered transient processes. The procedure used divides the considered cell plate into symmetrical finite difference grids with small reactant concentration difference. Initial conditions and boundary conditions are then utilized within an iterative process to obtain a solution for each grid that is subjected to the prespecified restrictions of the average boundary operation conditions and the input data, refer to Chapter V and Appendix, which can be listed as follows:

(a) Fuel flow rate and temperature

(b) Process air flow rate and temperature

(c) Coolant flow rate

(d) Oxygen utilization rate

(e) Hydrogen utilization rate

(f) Average cell plate temperature

The electrode current density variation is affected mainly by the concentration of oxygen and hydrogen inside the fuel cell during any transient process. However, the current density distribution is a function of the transient

temperature distribution of the electrode. As concluded in Chapter V the electrode temperature distribution is a function of the stack pressure, coolant volumetric flow rates and thermophysical properties.

This chapter is devoted to study the variation of the transient electrode current density distribution during start-up and shut-down process. For the sake of comparison the same cooling fluids flow rates and applied stack pressure used in the previous chapters results were utilized. The affects of these two important parameters on the electrode current density distribution were then presented by utilizing two-dimensions and three-dimensions contours figures.

### 6.1 Transient Electrode Current Density Distribution During a Start-Up Process

Figure 115 to Figure 120 exhibits the variation of the current density distribution with time in (Ampere/cm**2) for water Re=1250 and P=3500 Kpa which is the most critical case due to high thermal energy accumulation inside the fuel cell which causes the highest temperature increase rate in the electrode average temperature. Comparing Figure 121 to Figure 126, which represents the current density when water is used for the equal time intervals during a starting process the following is observed.

1. The highest local current densities are located close to fuel entrance upper edge during the start-up process but will shift slightly toward

the center of the electrode. During the start-up process the increase in the temperatures, before reaching the steady-state, will increase the generation rate of free electrons.

2. During a start-up process the increase in the coolant mass flow reduced the peak current density value and area and caused the peak area to shift further toward the upper edge close to fuel entrance side, as shown in Figure 127 to Figure 132 which represents the case where water was used with Re=6167 and P=0 Kpa.
3. The transient average current density for the electrode was affected negatively by the higher Re number and particularly with higher stack pressure after the first 20 minutes during the start-up process, before reaching the steady state, as shown by Figure 113. That also was related to the effect of the local temperature distribution.
4. When oil was used as a coolant similar observations were recorded. However, higher current density peak values and larger areas were noticed since oil as a cooling fluid with the law velocity restrictions was less efficient in removing thermal energy from the electrode plate and that caused the higher average current densities.

**Note: Each time interval represents 10 minutes.

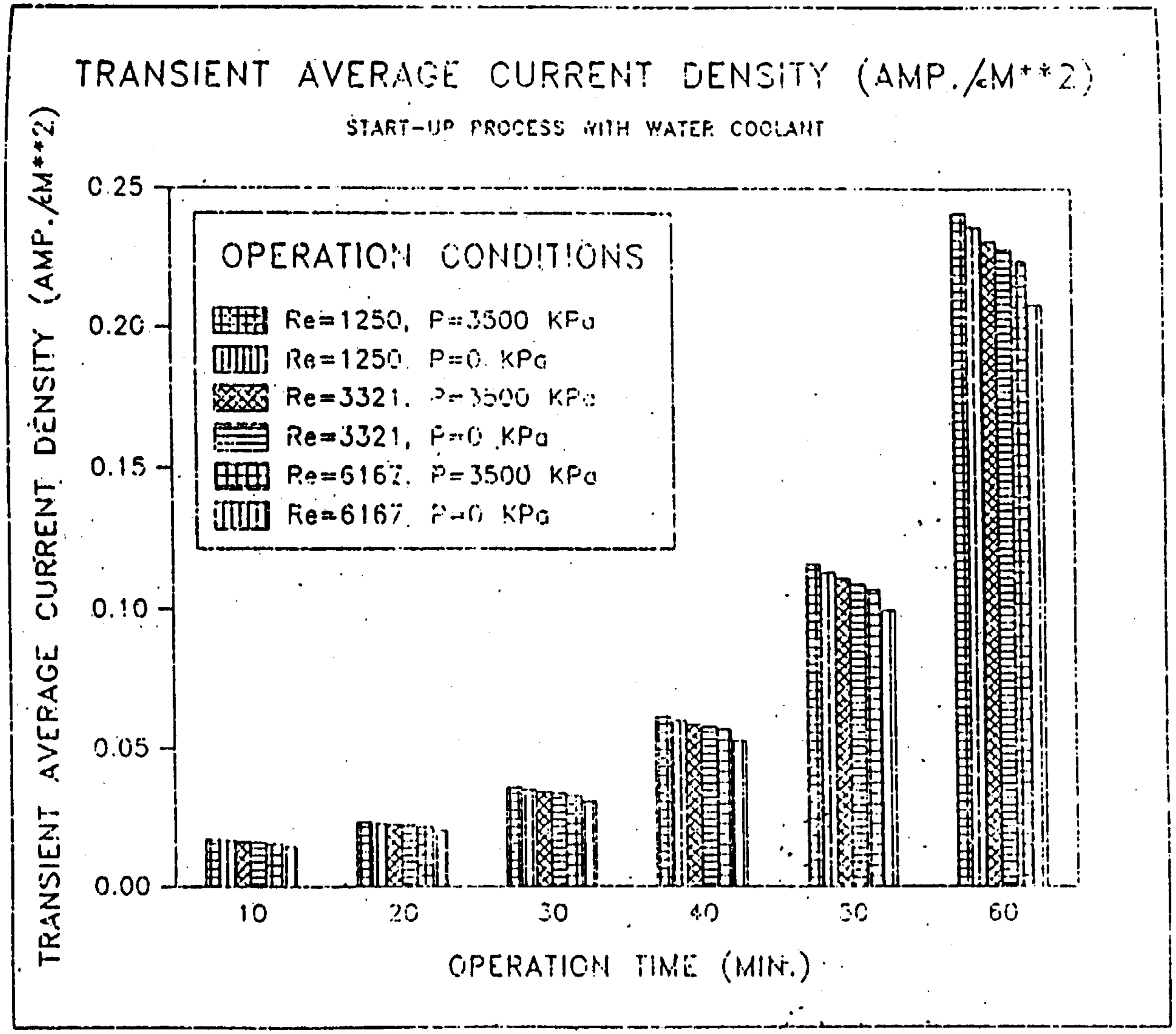


Figure 113. Transient Average Current Density During a Start-Up Process (Water Coolant).

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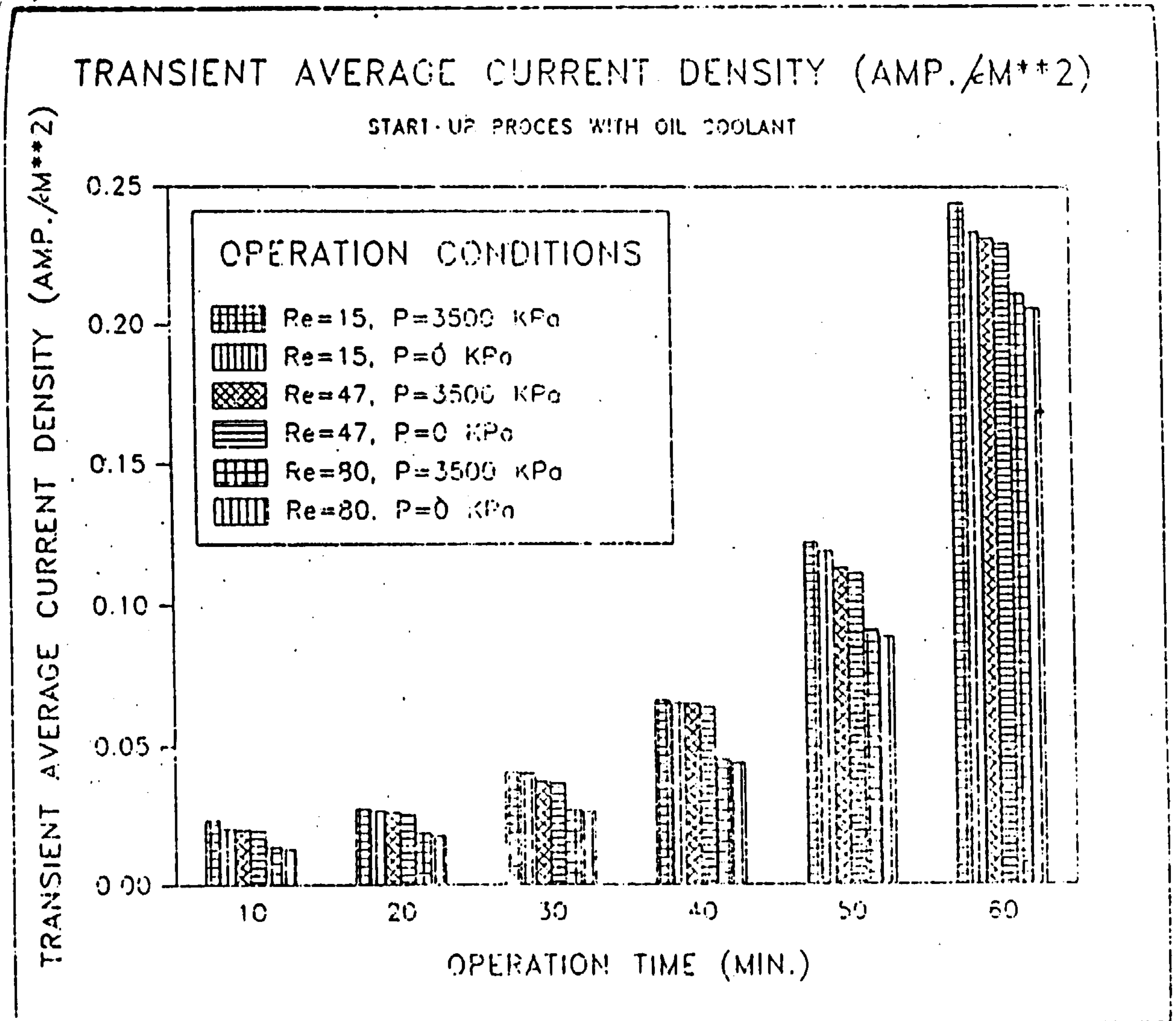
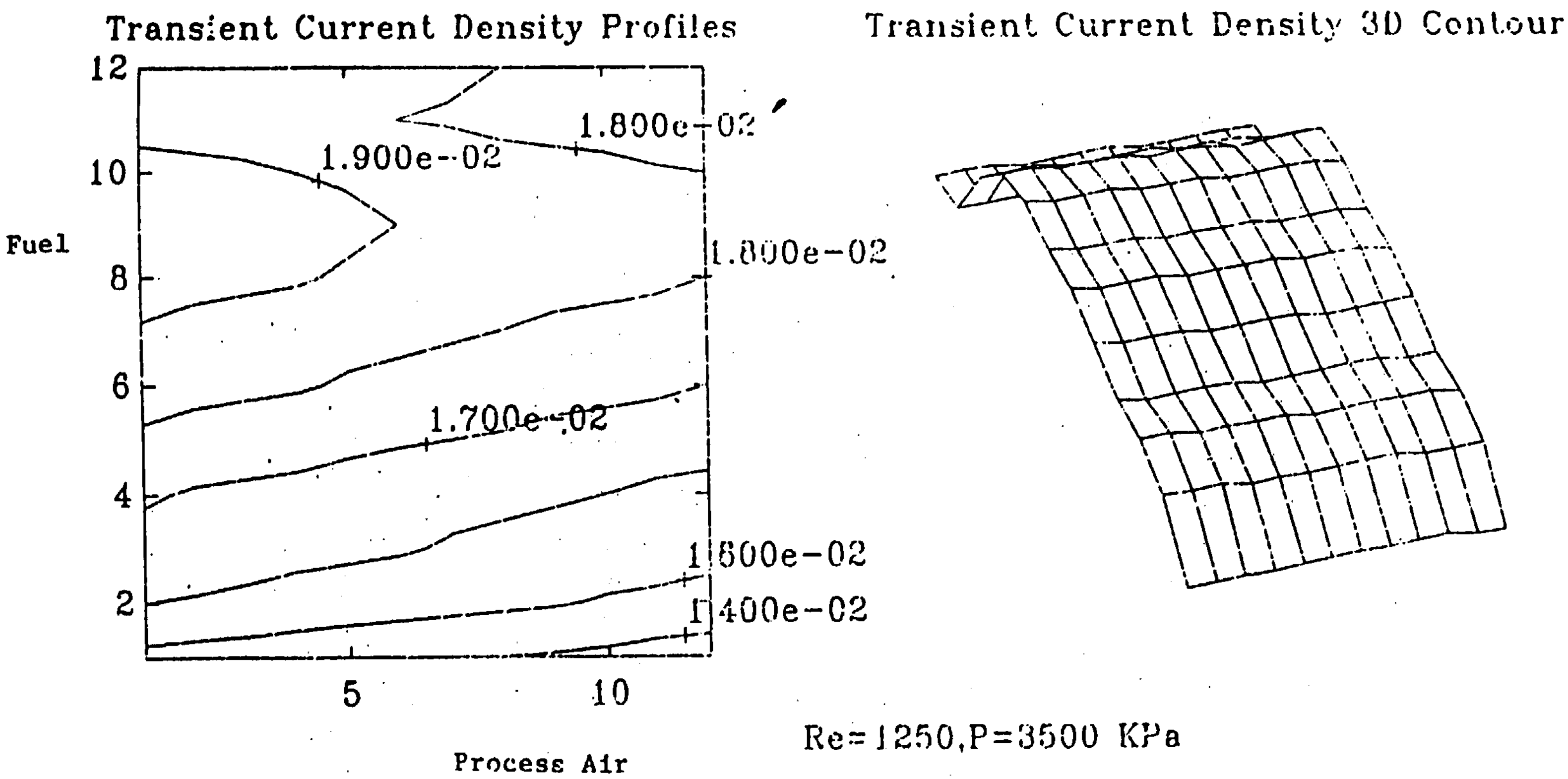



Figure 114. Transient Average Current Density During a Start-Up Process (Oil Coolant).

## TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

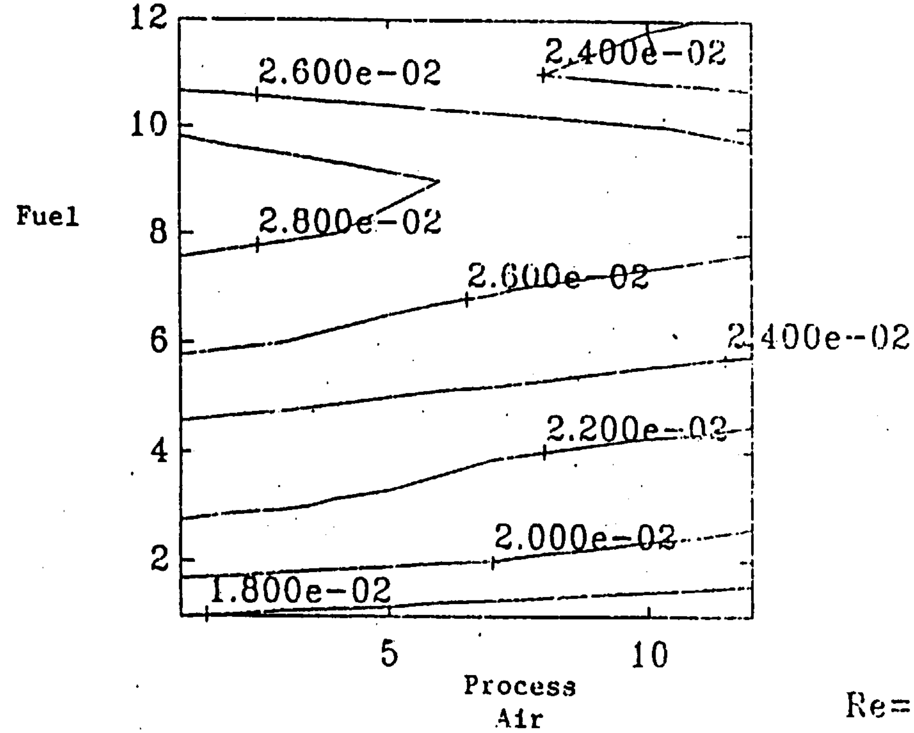
COOLING FLUID: WATER

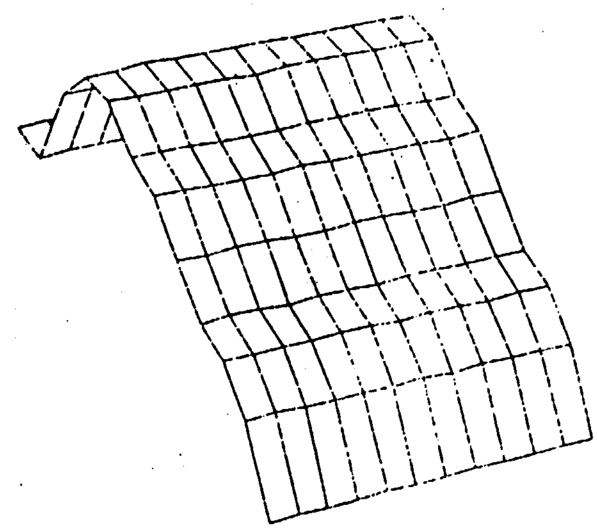
START-UP PROCESS

TIME INTERVAL NO.1

Figure 115. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=3500 KPa, Re=1250, T.I.=1).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

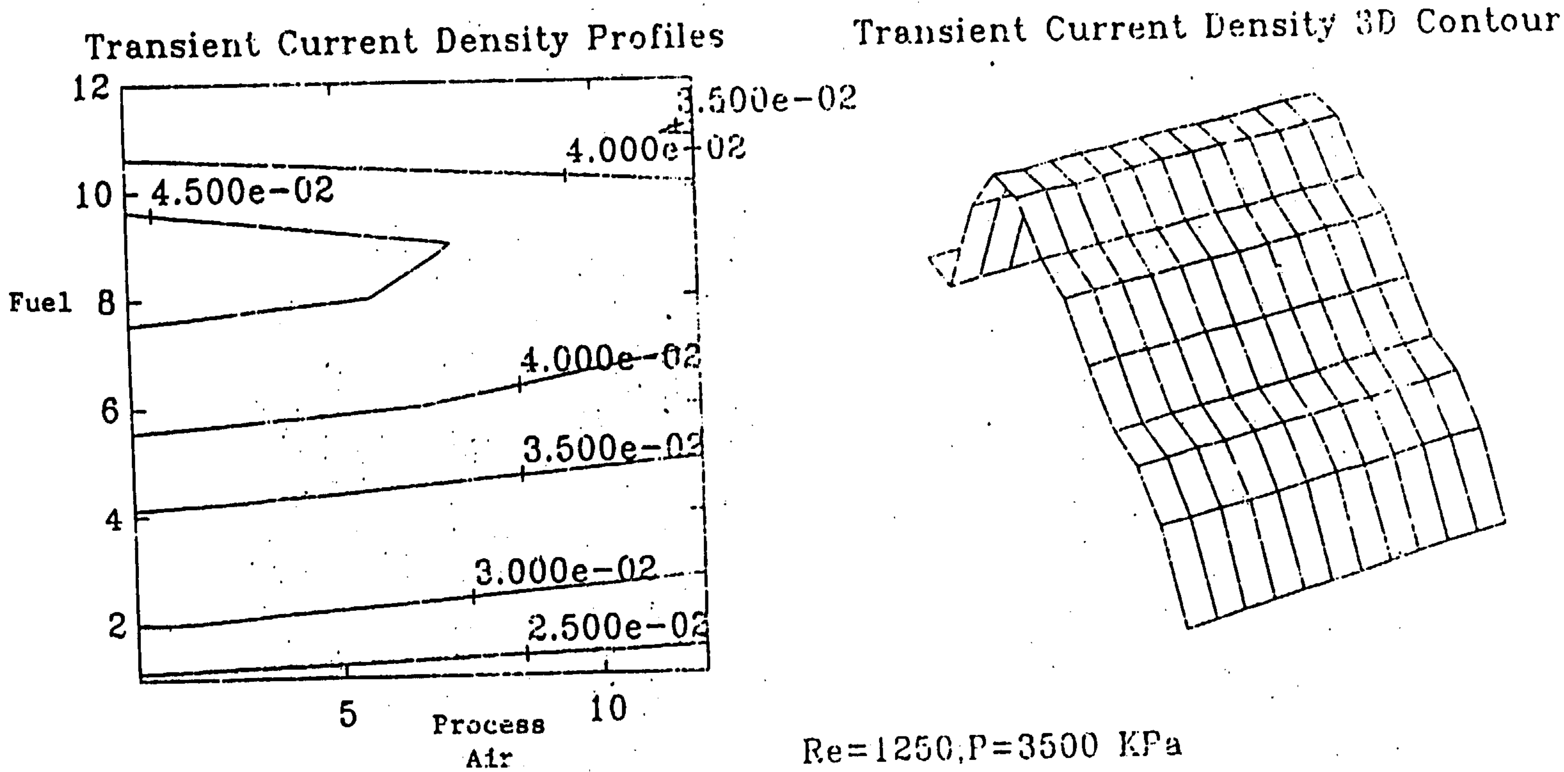
COOLING FLUID: WATER

START-UP PROCESS

TIME INTERVAL NO.2

Figure 116. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=3500 KPa, Re=1250, T.I.=2).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

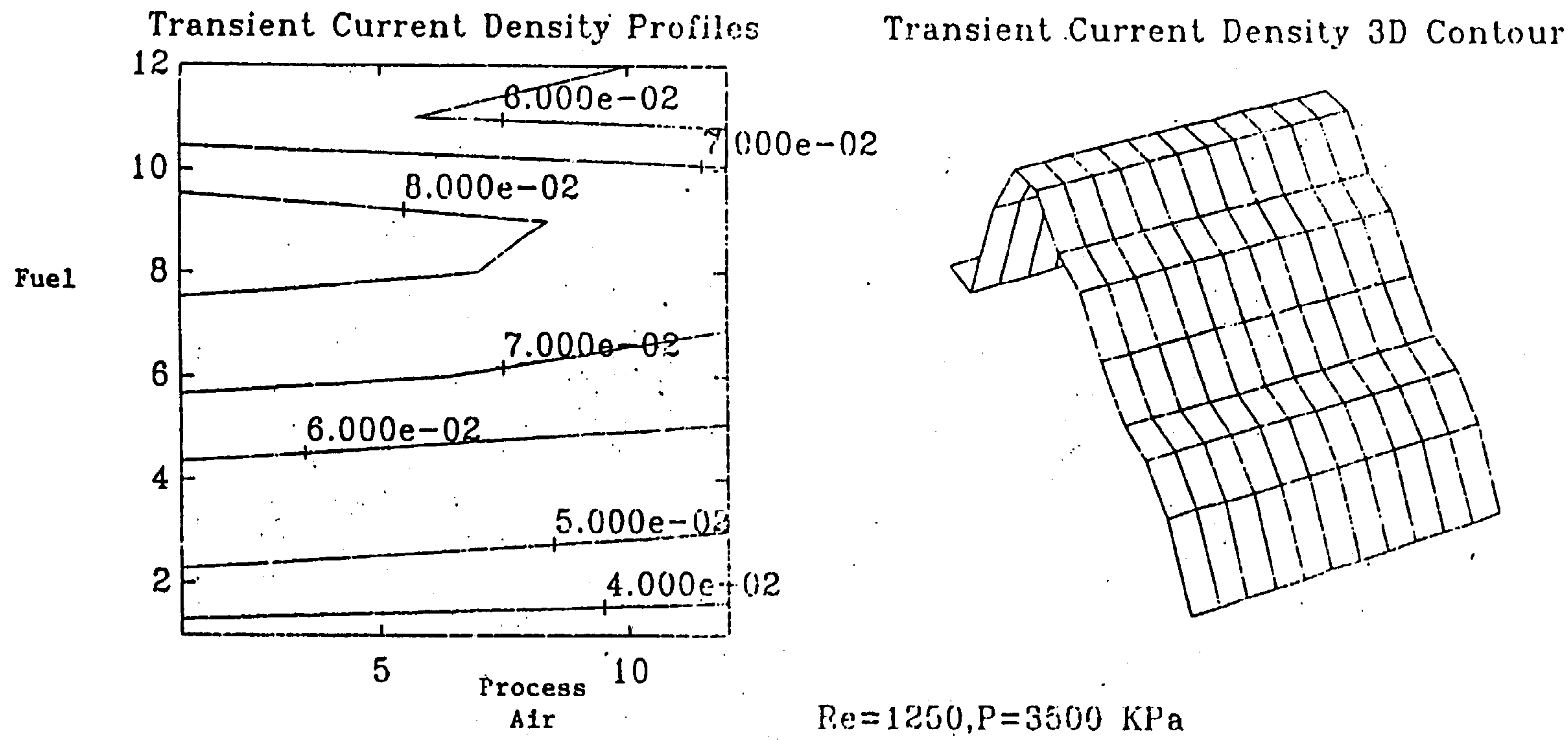
COOLING FLUID: WATER

START-UP PROCESS

TIME INTERVAL NO.3

Figure 117. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=3500 KPa, Re=1250, T.I.=3).

## TRANSIENT CURRENT DENSITY DISTRIBUTION

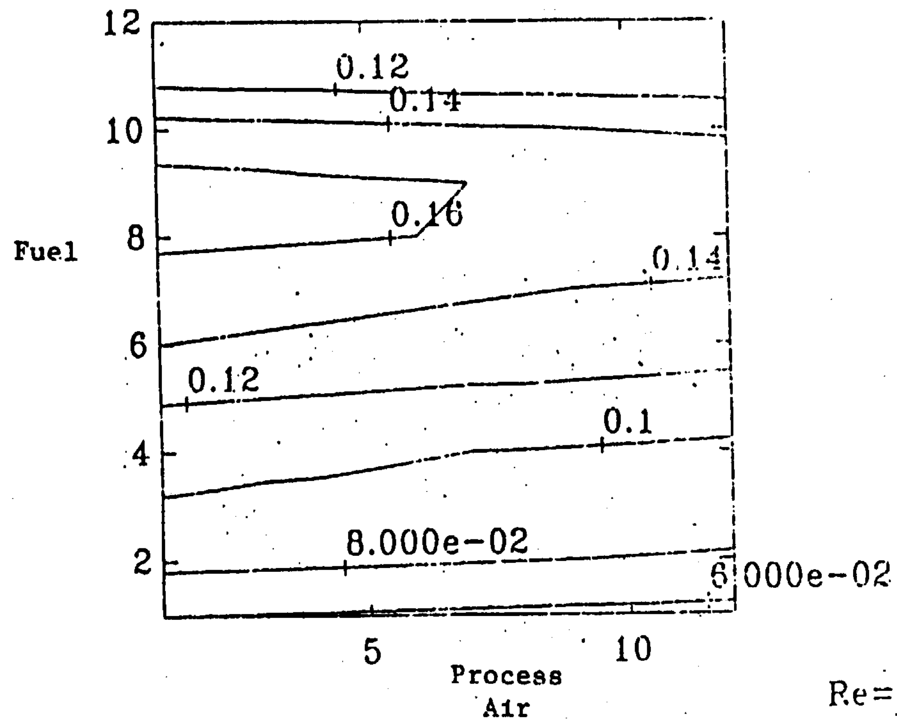



Re=1250,P=3500 KPa
COOLING FLUID: WATER
START-UP PROCESS
TIME INTERVAL NO.4

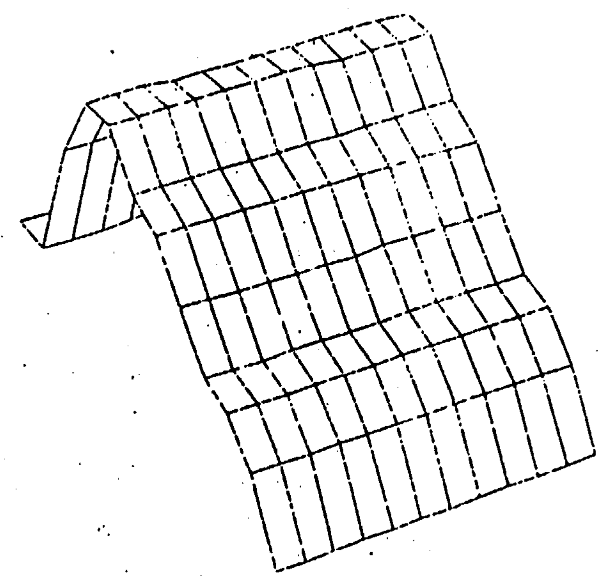
Figure 118. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=3500 KPa, Re=1250, T.I.=3).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

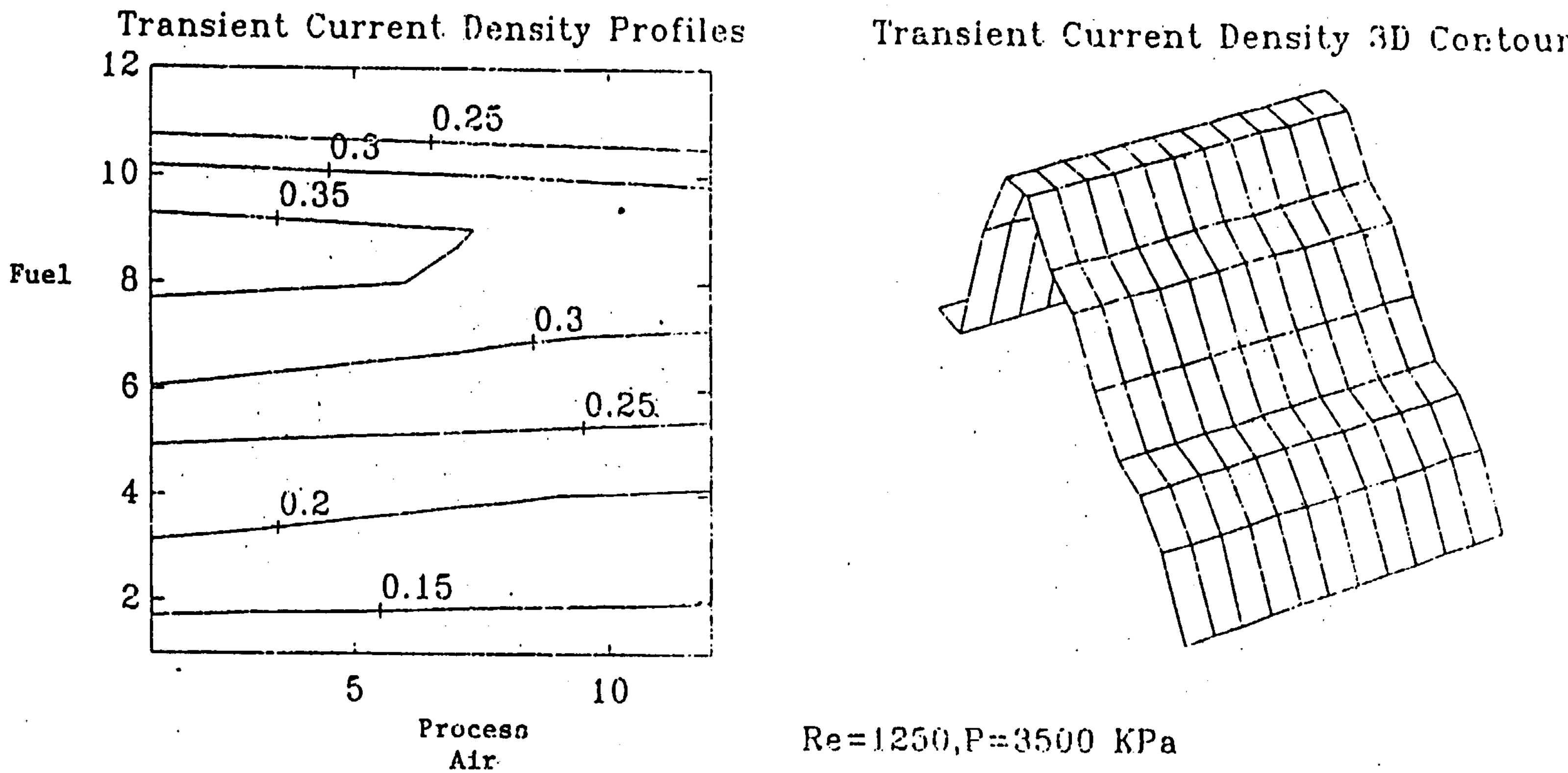
COOLING FLUID: WATER

START-UP PROCESS

TIME INTERVAL NO.5

Figure 119. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=3500 KPa, Re=1250, T.I.=5).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

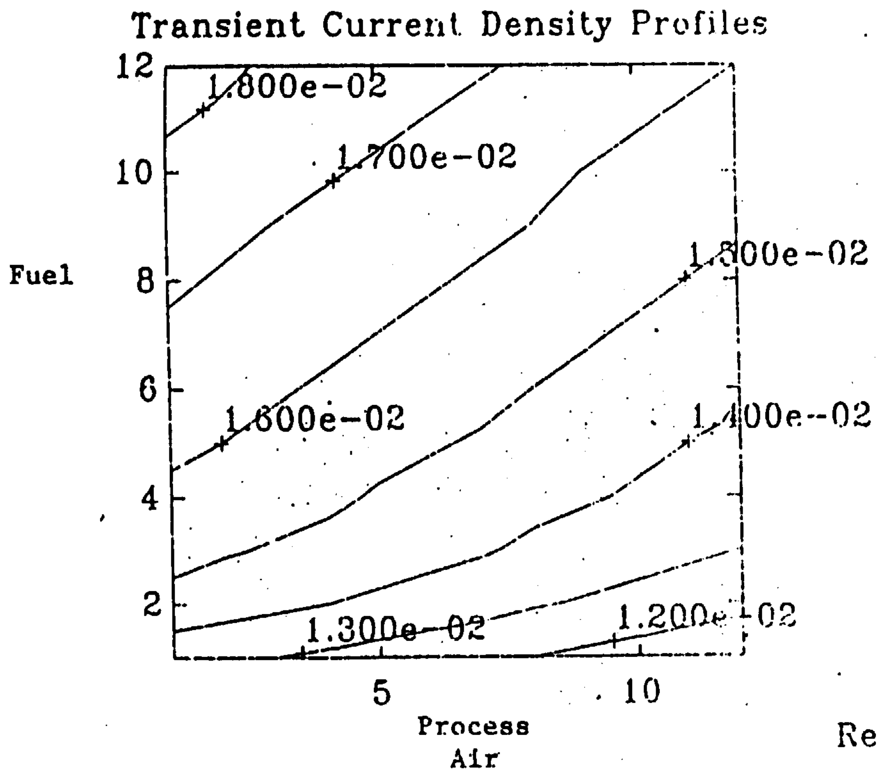
COOLING FLUID: WATER

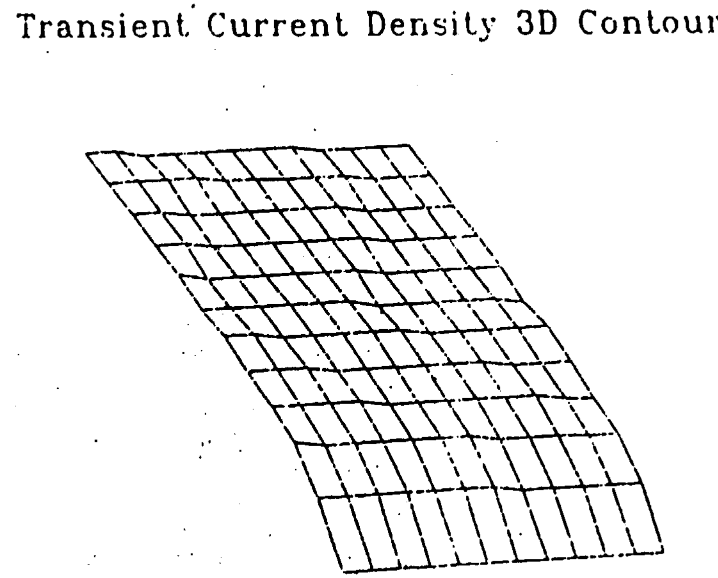
START-UP PROCESS

TIME INTERVAL NO.6

Figure 120. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=3500 KPa, Re=1250, T.I.=6).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=0 KPa

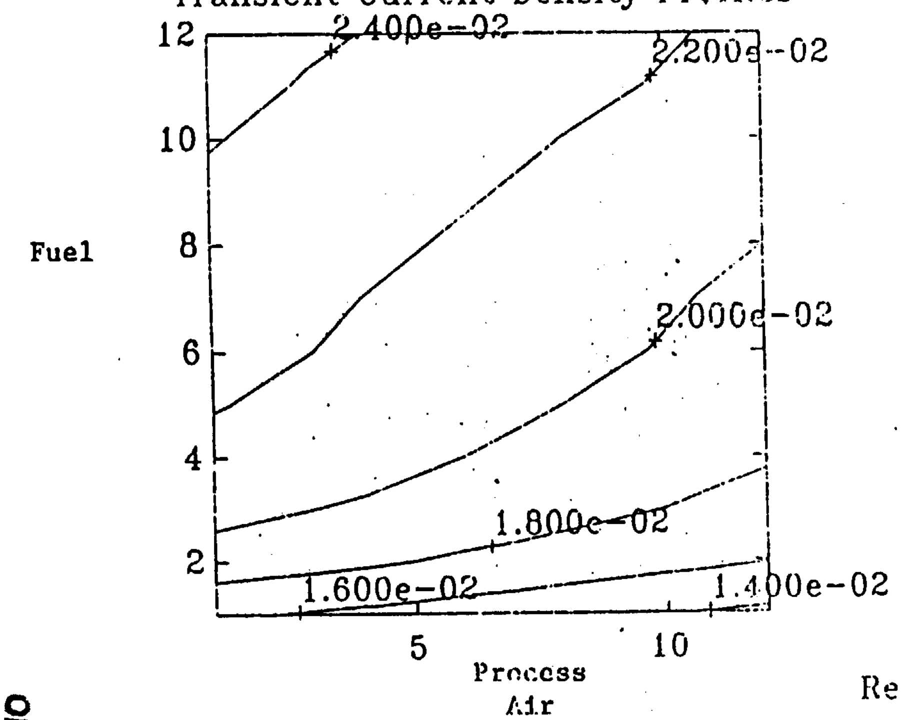
COOLING FLUID: WATER

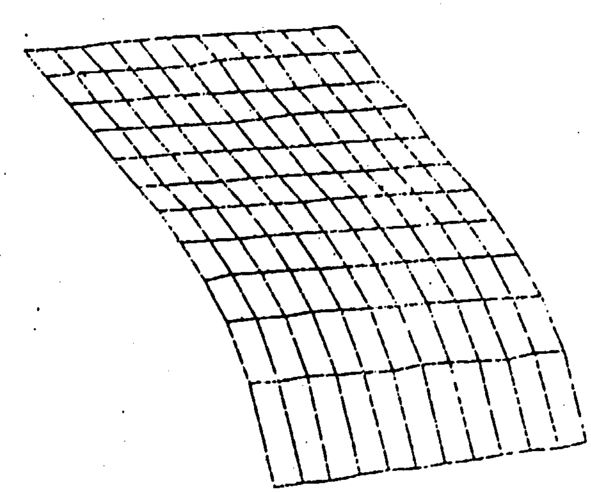
START-UP PROCESS

TIME INTERVAL NO.1

Figure 121. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=1250, T.I.=1).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=0 KPa

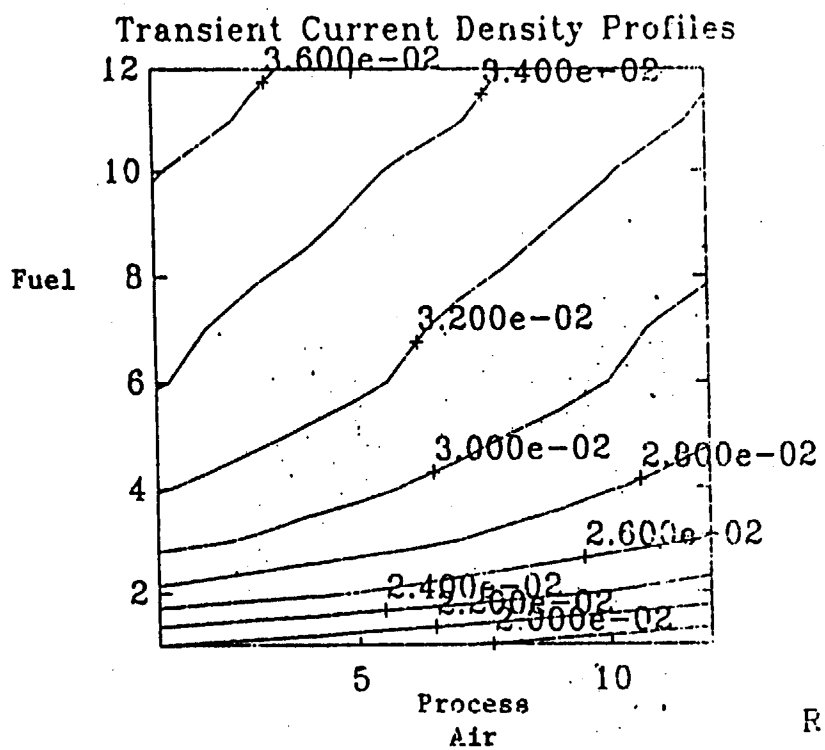
COOLING FLUID: WATER,

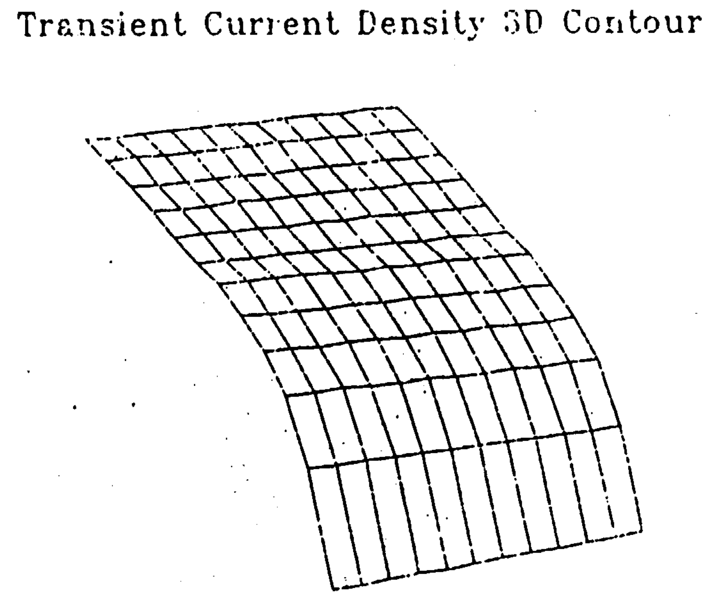
START--UP PROCESS

TIME INTERVAL NO.2

Table 122. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=1250, T.I.=2).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=0 KPa

COOLING FLUID: WATER

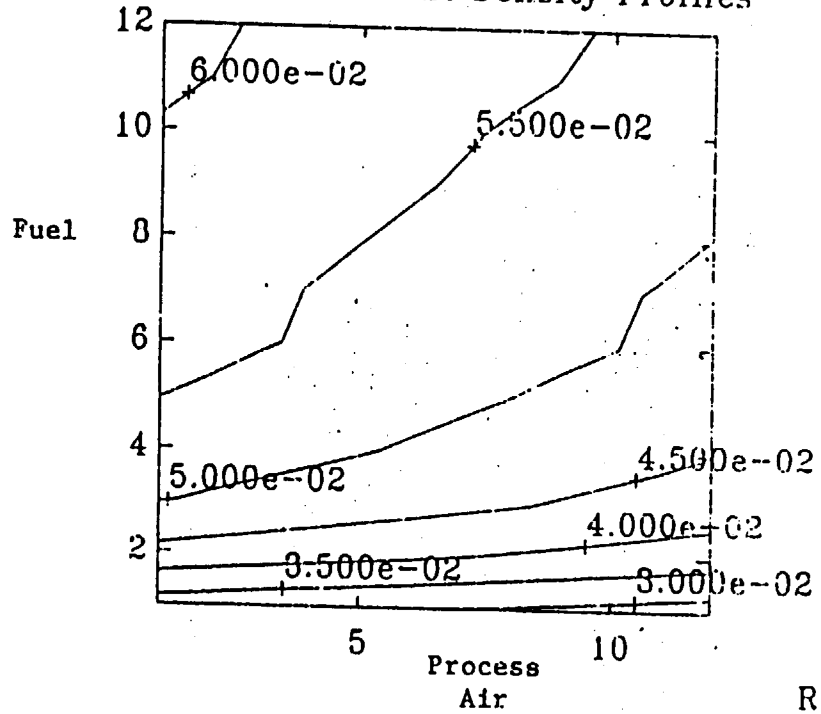
START-UP PROCESS

TIME INTERVAL NO.3

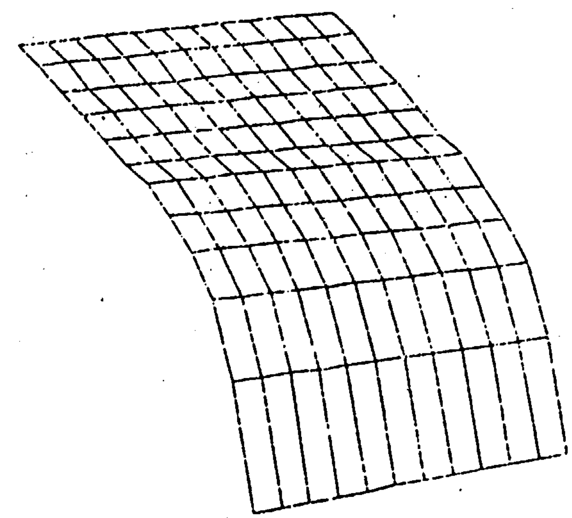
Table 123. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=1250, T.I.=3).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

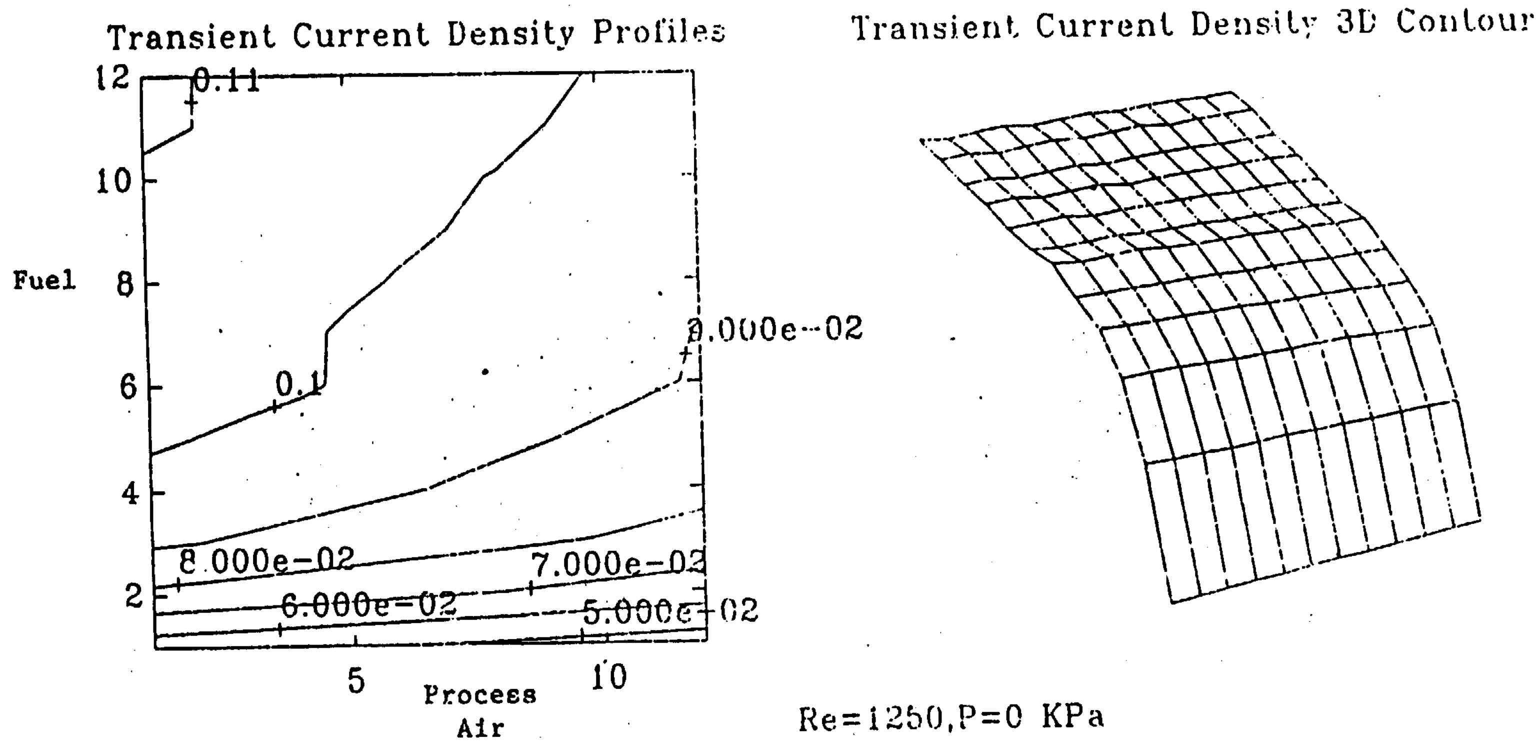
COOLING FLUID: WATER

START-UP PROCESS

TIME INTERVAL NO.4

Figure 124. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=1250, T.I.=4).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=0 KPa

COOLING FLUID: WATER

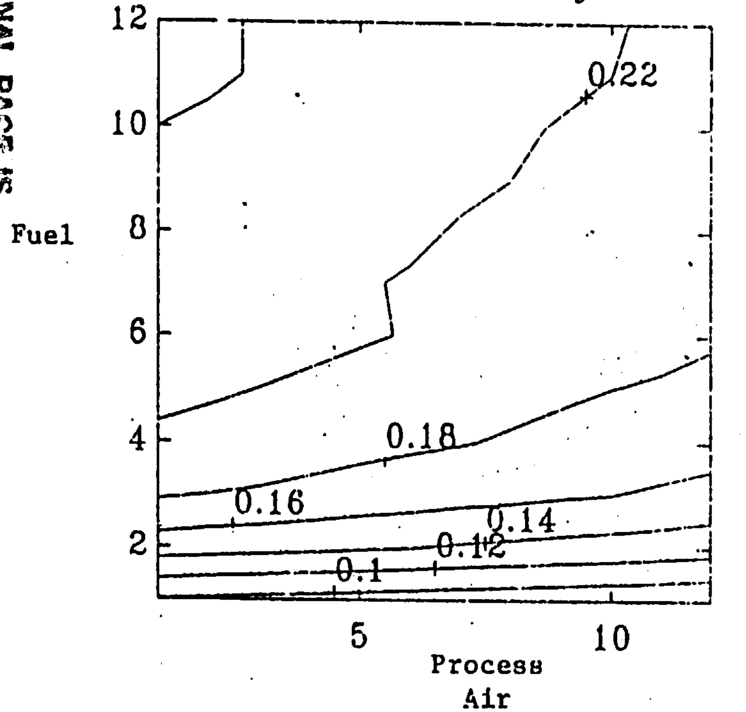
START-UP PROCESS

TIME INTERVAL NO.5

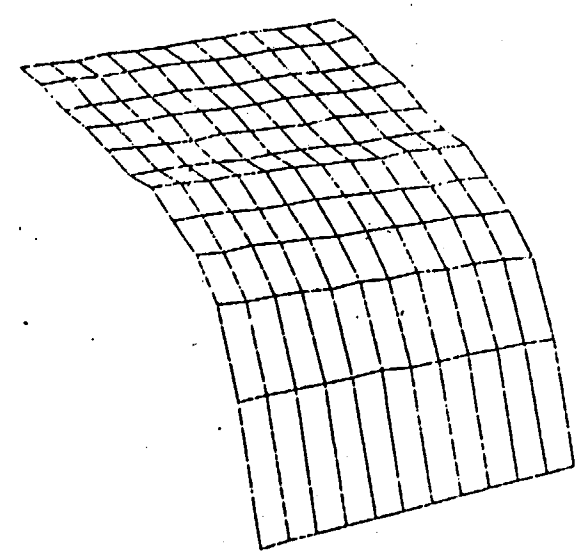
Figure 125. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=1250, T.I.=5).

## TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

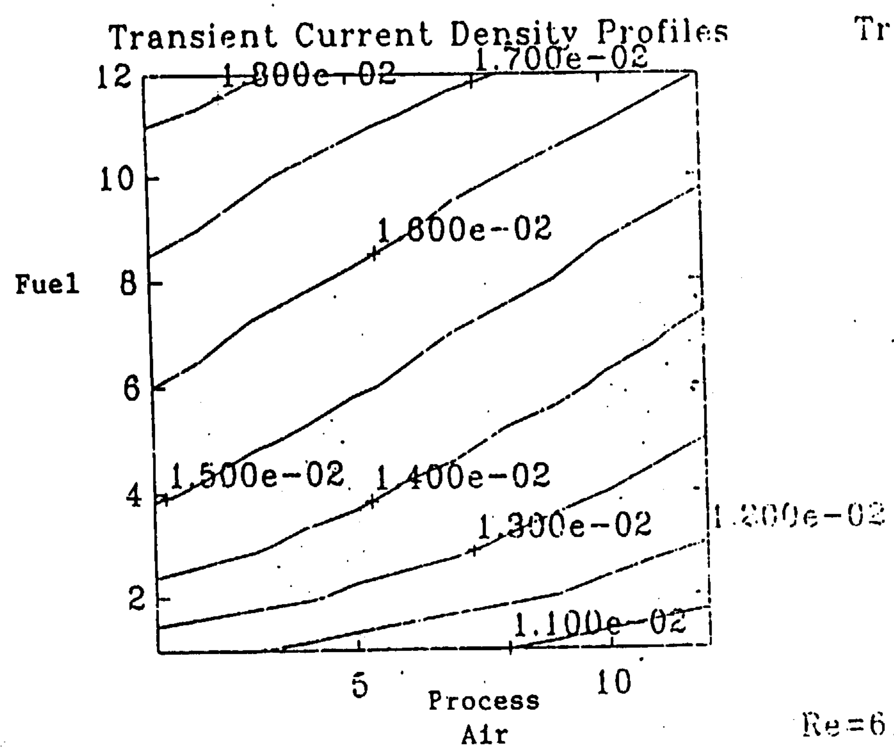
COOLING FLUID: WATER

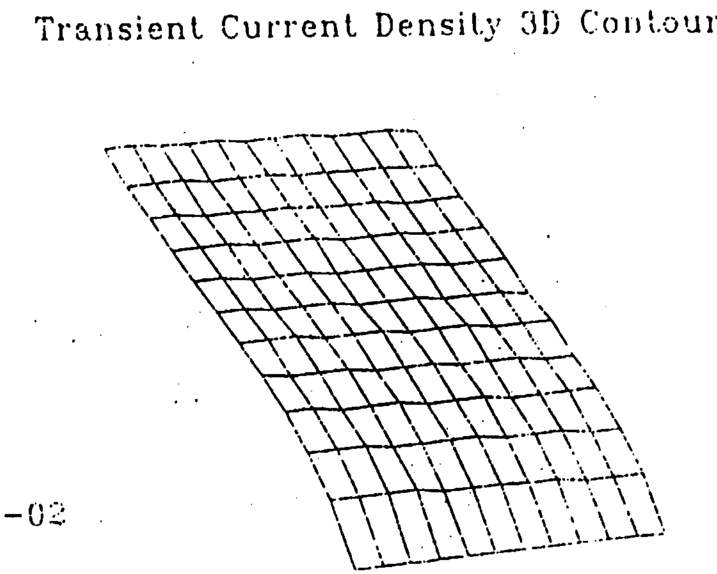
START-UP PROCESS

TIME INTERVAL NO.6

Figure 126. Transient Current Density Distribution During a Start-Up Process (Water Coolant. P=0 KPa, Re=1250, T.I.=6).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

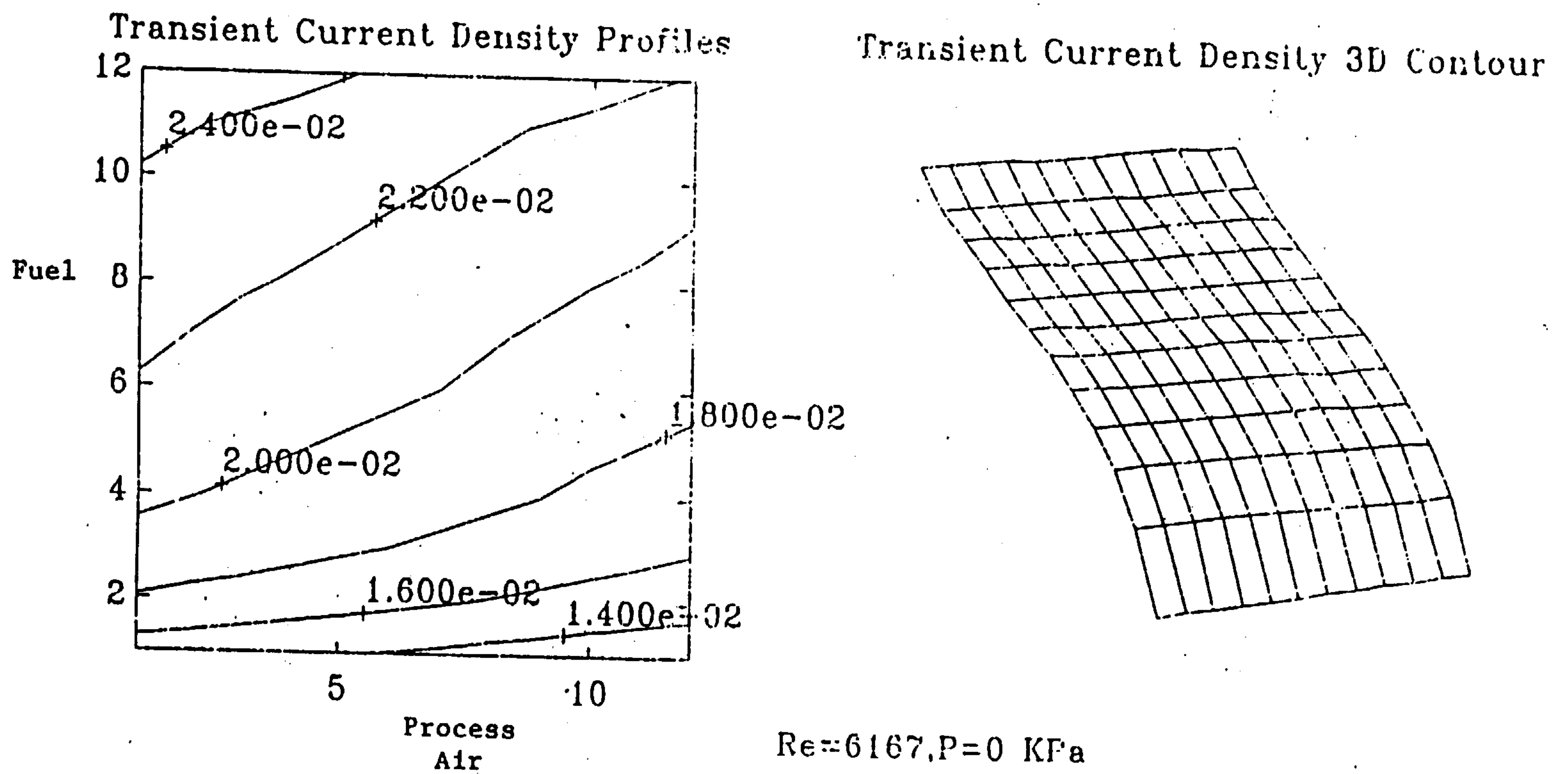
COOLING FLUID: WATER

START-UP PROCESS

TIME INTERVAL NO.1

Figure 127. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=6167, T.I.=1).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

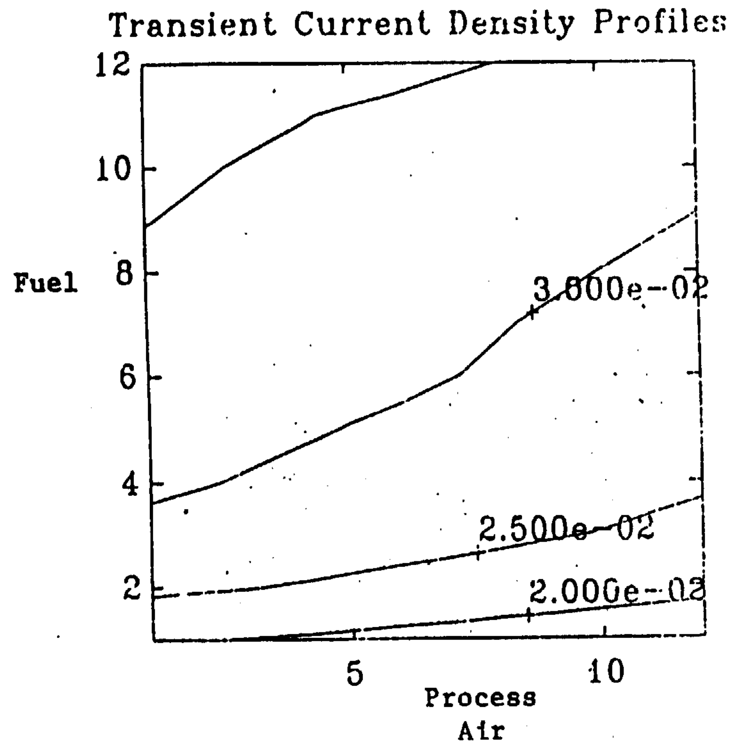
COOLING FLUID: WATER

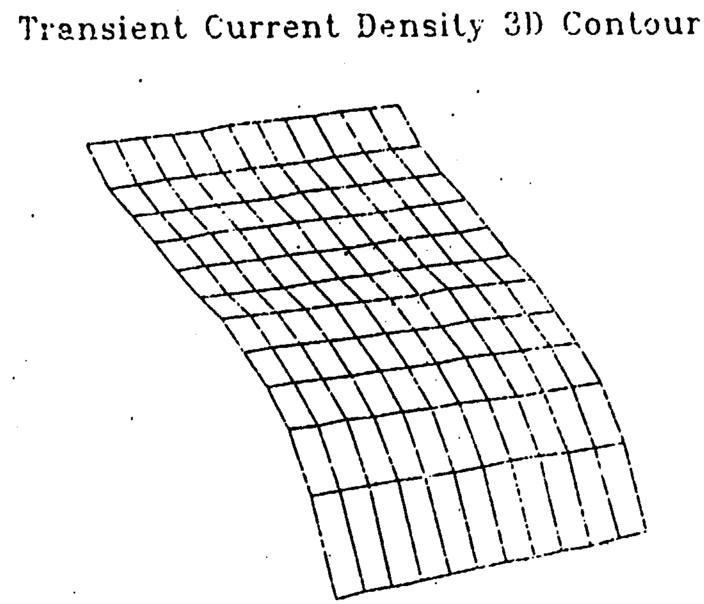
START-UP PROCESS

TIME INTERVAL NO.2

Figure 128. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=6167, T.I.=2).

## TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

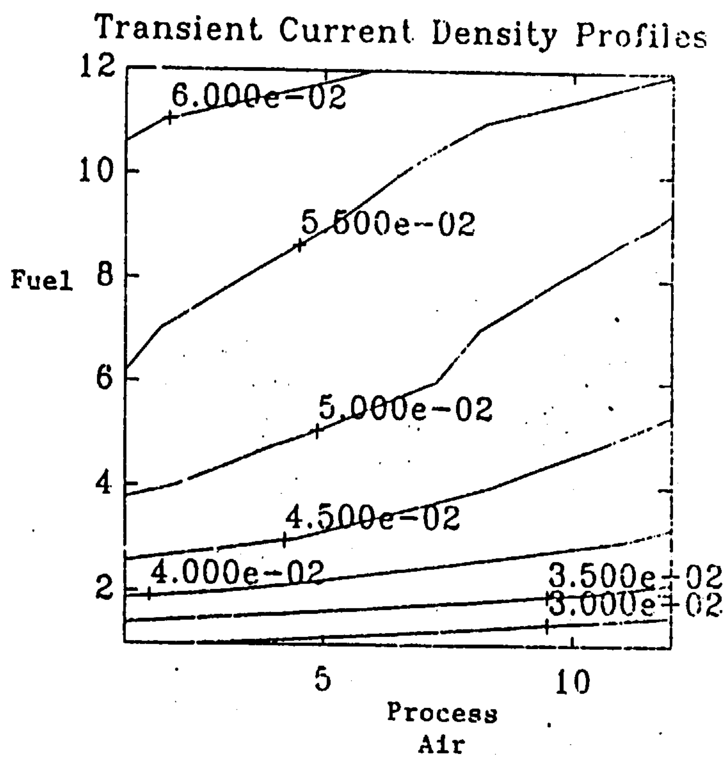
COOLING FLUID: WATER

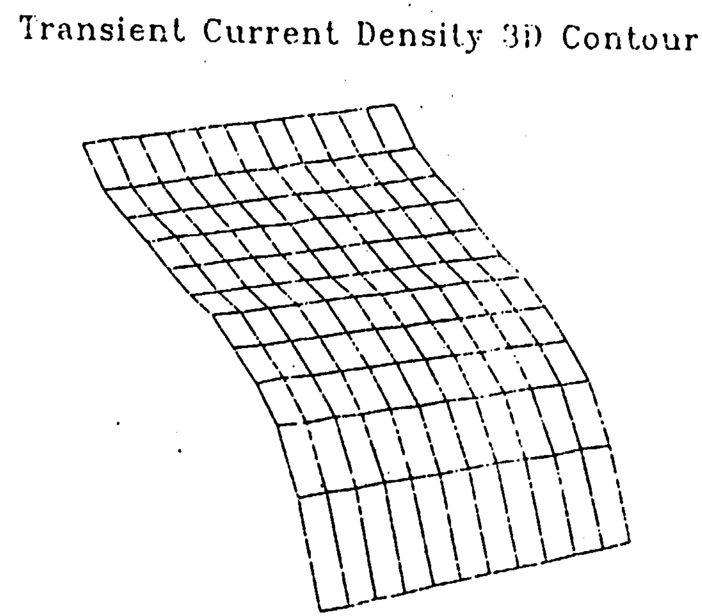
START-UP PROCESS

TIME INTERVAL NO.3

Figure 129. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=6167, T.I.=3).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

COOLING FLUID: WATER

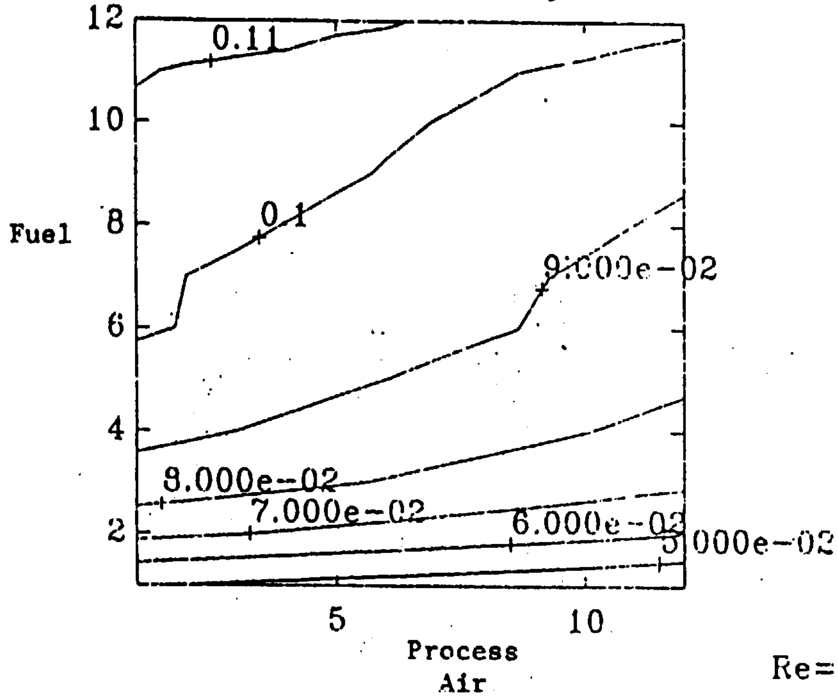
START-UP PROCESS

TIME INTERVAL NO.4

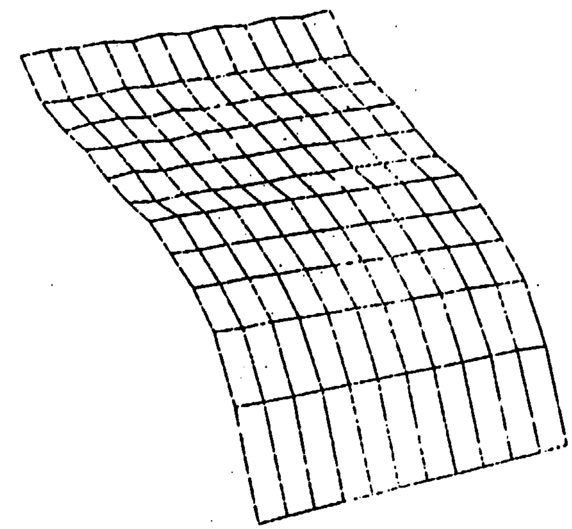
Figure 130. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=6167, T.I.=4).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=6167,P=0 KPa

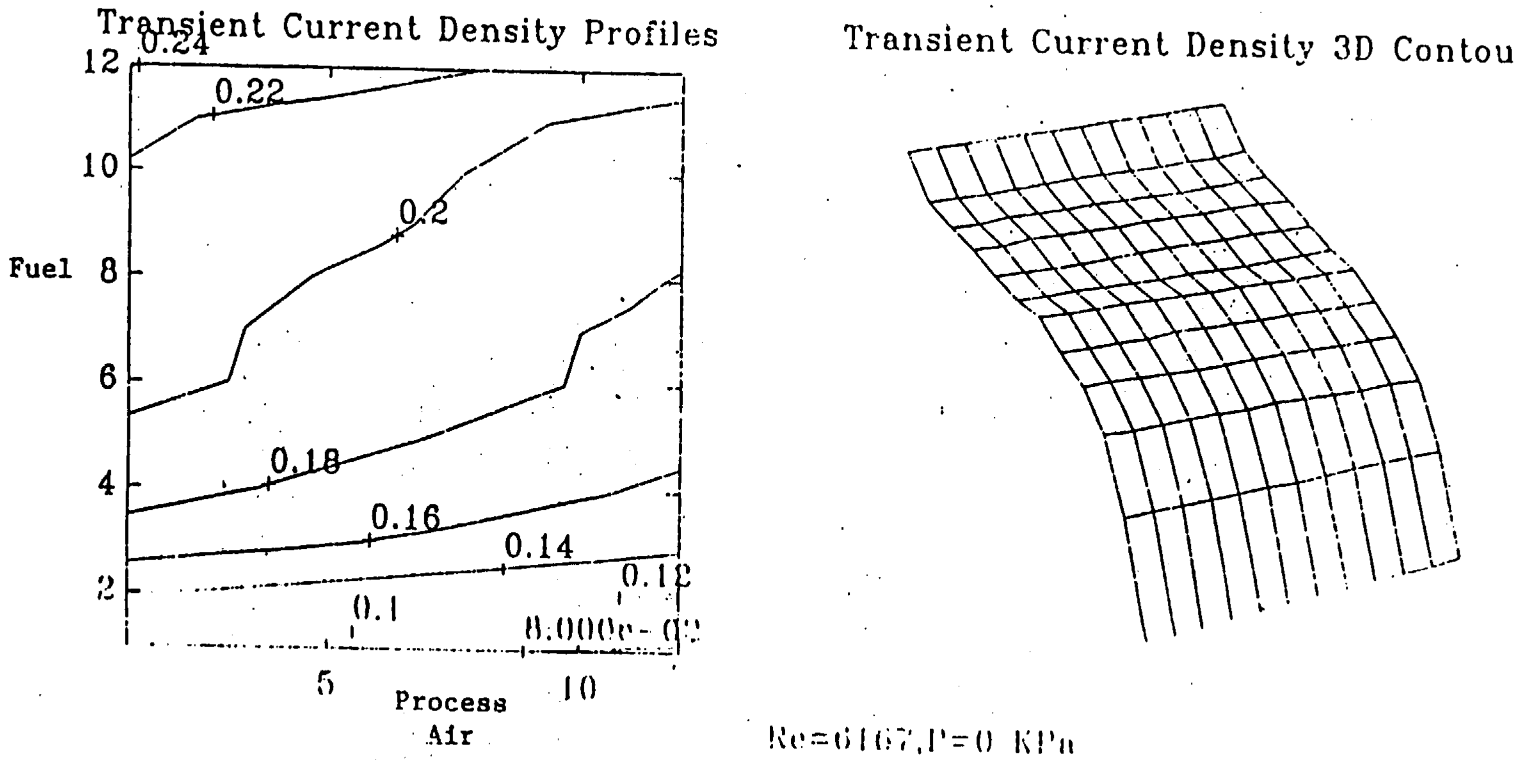
COOLING FLUID: WATER

START-UP PROCESS

TIME INTERVAL NO.5

Figure 131. Transient Current Density Distribution During a Start Up Process (Water Coolant, P=0 KPa, Re=6167, T.I.=5).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

COOLING FLUID: WATER

START-UP PROCESS

TIME INTERVAL NO.6

Figure 132. Transient Current Density Distribution During a Start-Up Process (Water Coolant, P=0 KPa, Re=6167, T.I.=6).

## 6.2 Transient Electrode Current Density Distribution During A Shut-Down Process

The same cases examined in the previous section are considered during a shut-down process in this section to determine the effect of the clamping pressure, coolant flow rate and thermophysical properties on the current density distributions. Referring to Figure D-1 to Figure D-13 in the Appendix, for water with Re=1250 and clamping pressure of 3500 KPa, and Figure D-14 to Figure D-27 for the same flow rate and cooling fluid but with zero applied stack pressure, the following can be observed:

1. The current density decrease rate is higher than the accompanied temperature decrease rate.
2. The peak areas of the current density shifted to the center of the plates and with maximum clamping pressure.
3. Figure 133 which exhibits the variation of the average current density of the plate, demonstrates the reduction of that value for the most extreme case considered, minimum flow rate and maximum clamping pressure, when compared to the minumum flow rate and zero applied stack pressure case. This can be related to the effect of the electrode plate temperature distribution.
4. The increase in the average current density when increasing the mass flow rate was not

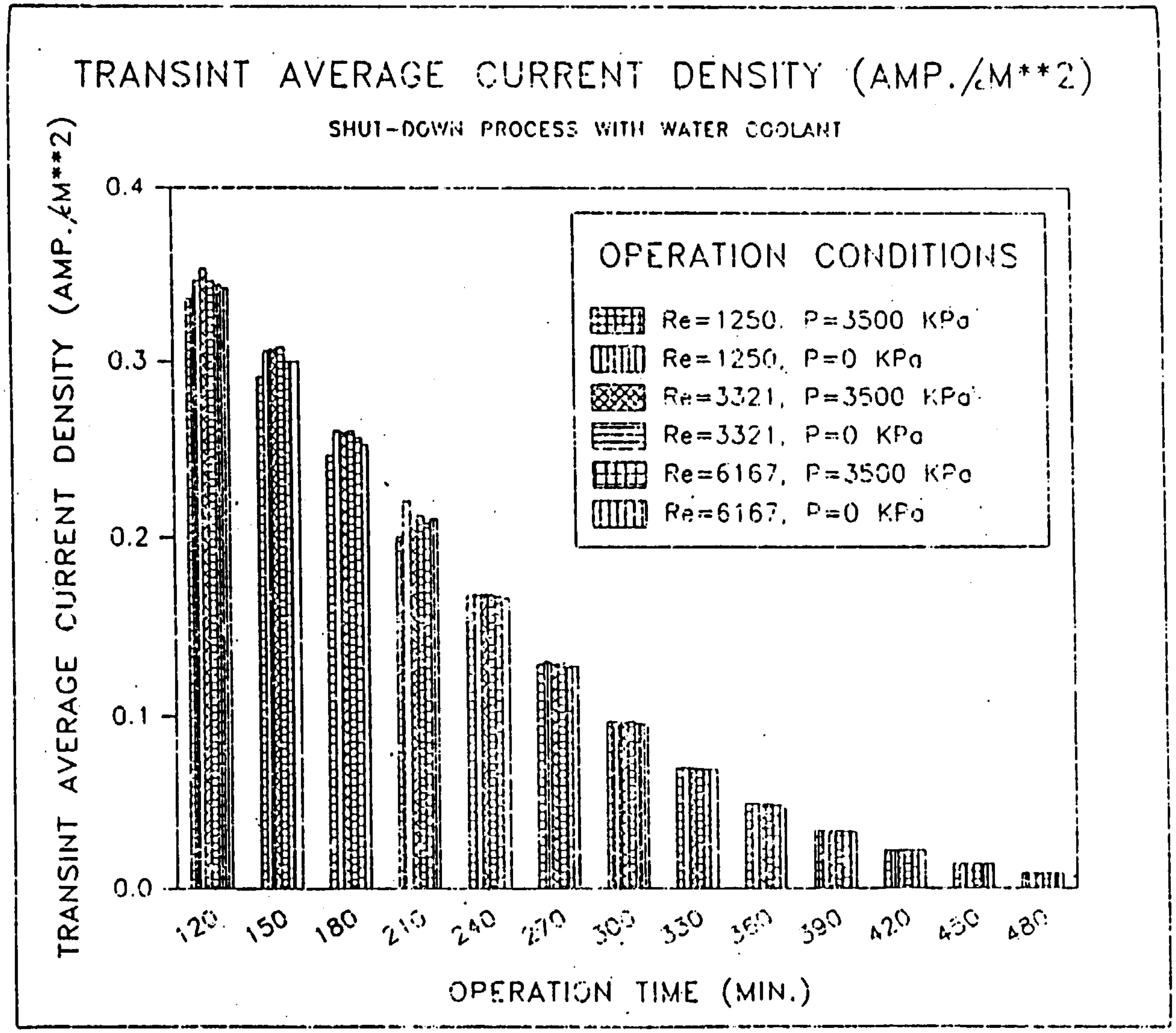



Figure 133. Transient Average Current Density During a Shut-Down Process (Water Coolant).

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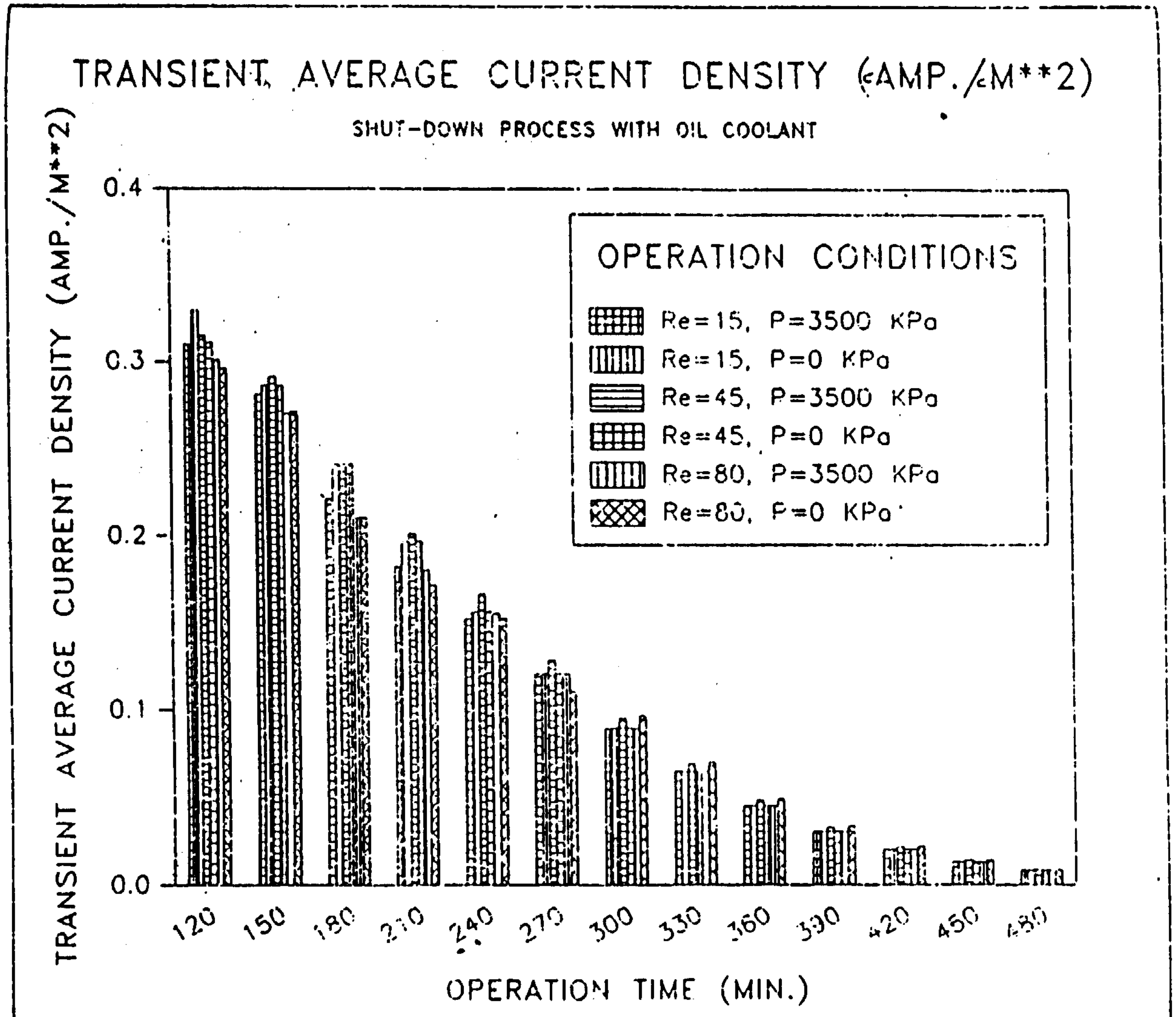


Figure 134. Transient Average Current Density During a Shut-Down Process (Oil Coolant).

as high as that when reducing the clamping pressure during the shut-down process.

5. Similar observations were recorded when oil was used as a cooling fluid. However, the average transient current density drop rate was higher than that when water was used as a coolant due to the coolant volumetric flow restriction which affected negatively the efficiency of the cooling system in heat removal during the shut-down process as shown in Figure 134.

# CHAPTER VII

## DISCUSSION OF RESULTS AND ACCURACY ANALYSIS

This chapter is devoted to the analysis and interpretation of the experimental and theoretical results obtained in the previous chapters. These analyses and interpretations will be mostly concerned with the effects of clamping pressures, cooling fluid flow characteristics, thermophysical properties and the transient heat transfer characteristic on the performance of a PAFC power plant operating under transient conditions.

A good method of presenting the gathered information and forming a clear picture of the effects of each considered parameter on the fuel cell transient heat transfer rates is experimental and analytical results comparison.

Figure 135 shows the overall heat transfer coefficient as a function of time for both cooling fluids for a start-up and shut-down cases respectively, with average (Re) number and stack pressure conditions. An obvious increase in the values of the overall heat transfer coefficient was noticed with higher applied stack pressure as mentioned in Chapter IV, however, that increase in the case of water was higher than that of oil. The average difference was 28.392%

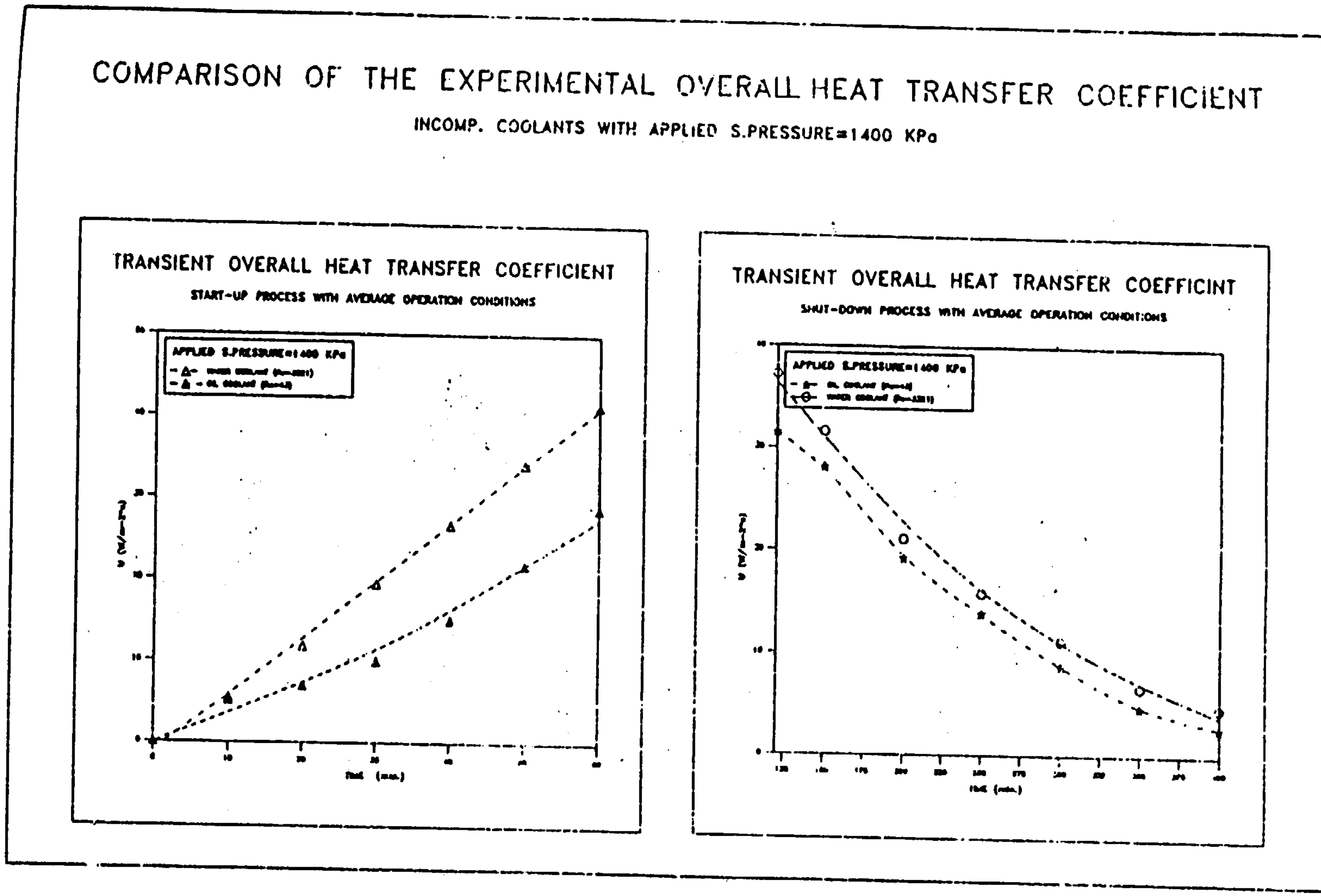


Figure 135. Comparisons of the Experimental Overall Heat Transfer Coefficient.

during a start-up process and approximately 16.524% during a shut-down process. The higher U value for water was not solely due to the different cooling fluid thermophysical properties but also due to the large difference of the fluid velocity. That difference affected the results since the transient overall heat transfer is a function of the convection heat transfer coefficient which is dependent on the flow characteristics. It should be noticed that the data obtained for water was for mass flow rates covering laminar and turbulent flows but only the laminar flow condition was considered in the oil case.

The effect of pressure on the reduction of the thermal contact resistance is significant for all the cases considered for each coolant, as demonstrated in Chapter IV. This reduction in the thermal resistance is mainly due to the increase of the contact common surface area between the fuel cell plate and the cooling plate which was caused by the plastic deformation of the two surfaces and the reduction of the air-occupied gaps due to surfaces roughness. The significant effect of the thermal contact resistance on the overall transient heat transfer coefficient can be demonstrated clearly by monitoring the variation of the ratio I(t) with time, where I(t) can be defined as:

$$I(t) = U(t)/V(t) = \frac{\text{transient overall heat transfer coefficient of the fuel cell model}}{\text{transient overall heat transfer coefficient neglecting the effect of the thermal contact resistance.}}$$

C-4.

or

$$I(t) = \frac{[(\frac{x_1}{K}) + (\frac{x_2}{K}) + (\frac{1}{h(t)})])}{[(\frac{x_1}{K}) + (r_c) + \frac{x_2}{K}) + (\frac{1}{h(t)})]}$$

Utilizing the experimental correlation to generate the results for both U-values a remarkable difference was noticed, as shown by Figure 136 and Figure 137 for water during start-up and shut-down process respectively, for several considered applied stack pressure. It was noticed that the difference reached a maximum of 10.383% for the considered start-up process and 10.109% for the considered shut-down process. In the case of oil coolant the maximum difference was 9.921% for start-up conditions and 9.844% for the shut-down conditions for the same pressure ranges.

An increase in the values of the Nusselt number was noticed for both cooling fluid with high applied stack pressure, (please refer to Appendix A and B). That is mainly due to the effect of the stack pressure on the surface temperature. Also, the Nusselt number increased with increasing the coolant volumetric flow rate for both coolants. However, the increase in the oil Nusselt number case was higher than that for water. This can be shown by dividing the average difference of the Nusselt number values measured during a start-up process for the maximum and minimum coolant volumetric flow rate by the total difference in the Re number. That non-dimensional ratio was $7.692*10^{-3}$

for oil and $9.152*10^{-6}$ for water. Figure 138 represents a comparison between the transient variation of the experimental Nusselt number for both coolants with average operation conditions during a start-up and shut-down process respectively.

This is because higher stack pressure results in decreasing the thermal contact resistance between the heating elements and the electrode plate. This in turn results in an increase in the electrode internal energy and electrode temperature. However, the rate of heat transfer electrode from the electrode plate to the coolant is not equivalent to the rate of increase of the electrode internal energy. This is because of a significant thermal contact resistance between the electrode plate and the cooling plate even after increasing the stack pressure. This results in the accumulation of internal energy in the electrode plate which results in an increase of the electrode plate temperature.

The increase in the average cell temperature rate was greater and the average temperature measured was higher in the case of oil coolant during the considered start-up process due to the lower Re number used in the case of oil as demonstrated in Chapter V. On the other hand during shut-down process the average transient temperature drop rate was slower for oil than that for water. That is basically due to the higher accumulation rates of the internally generated thermal energy when oil is used as a

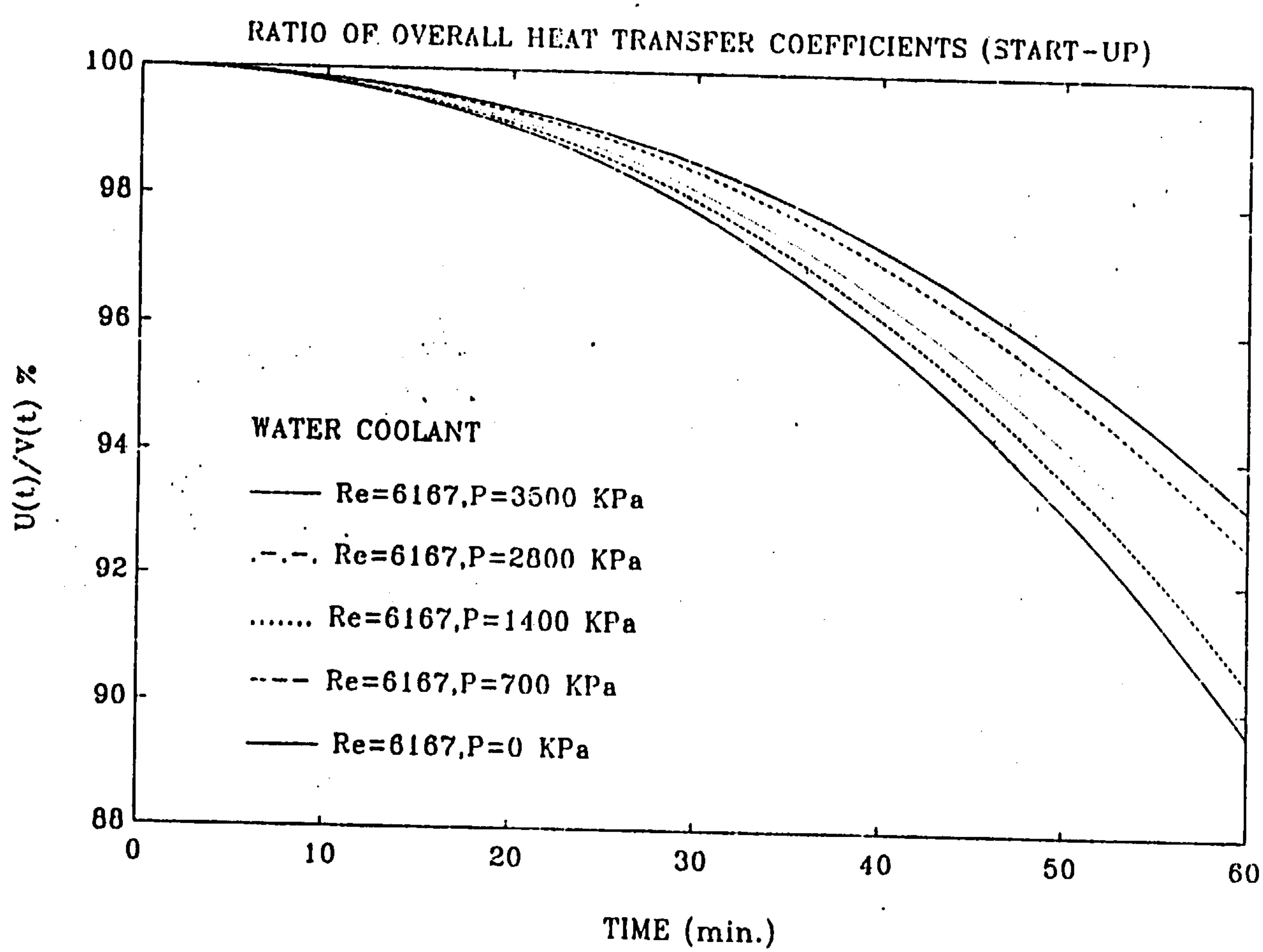


Figure 136. I(t) Ratio (Water, Start-Up).

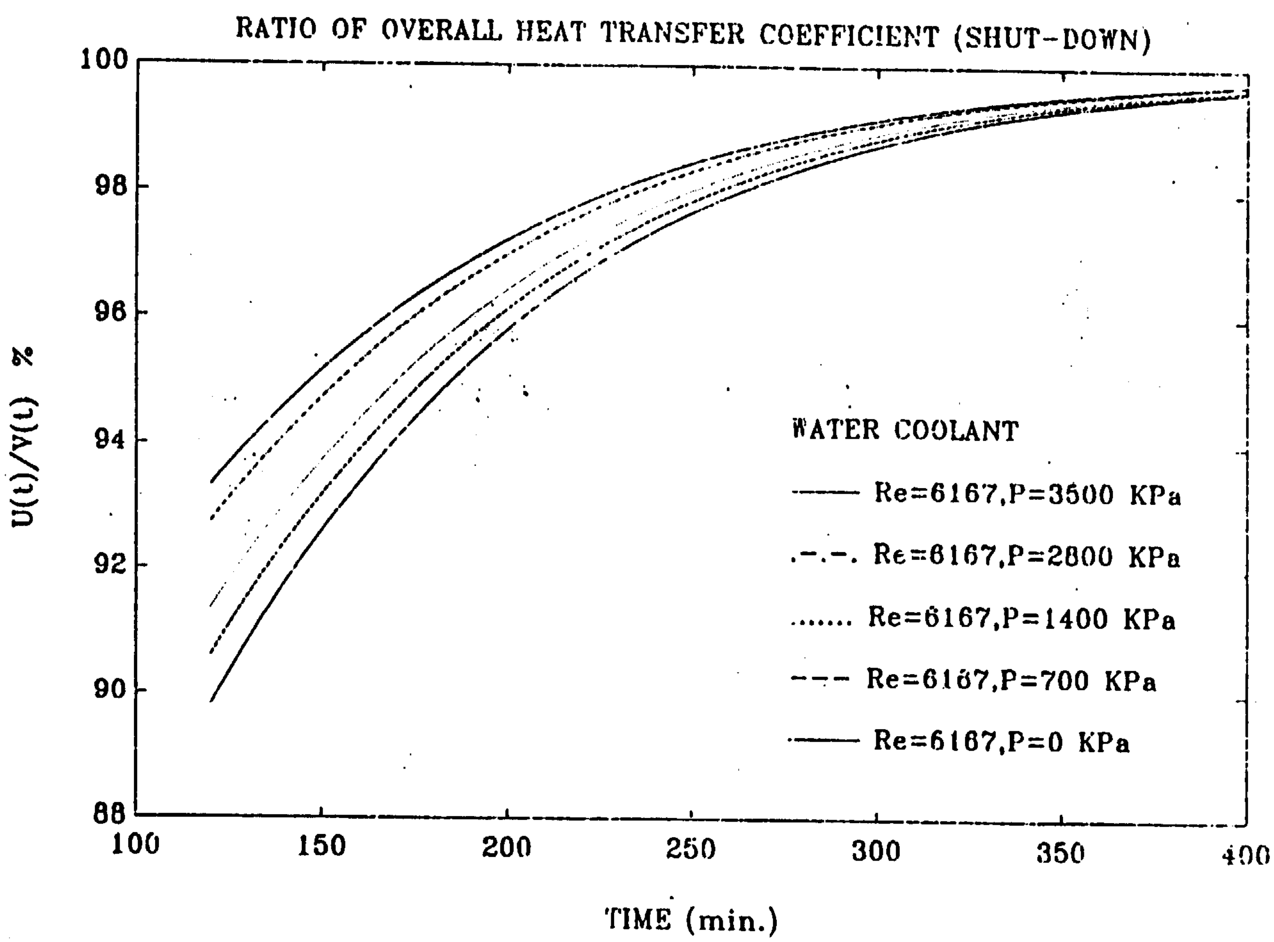


Figure 137. I(t) Ratio (Water, Shut-Down).

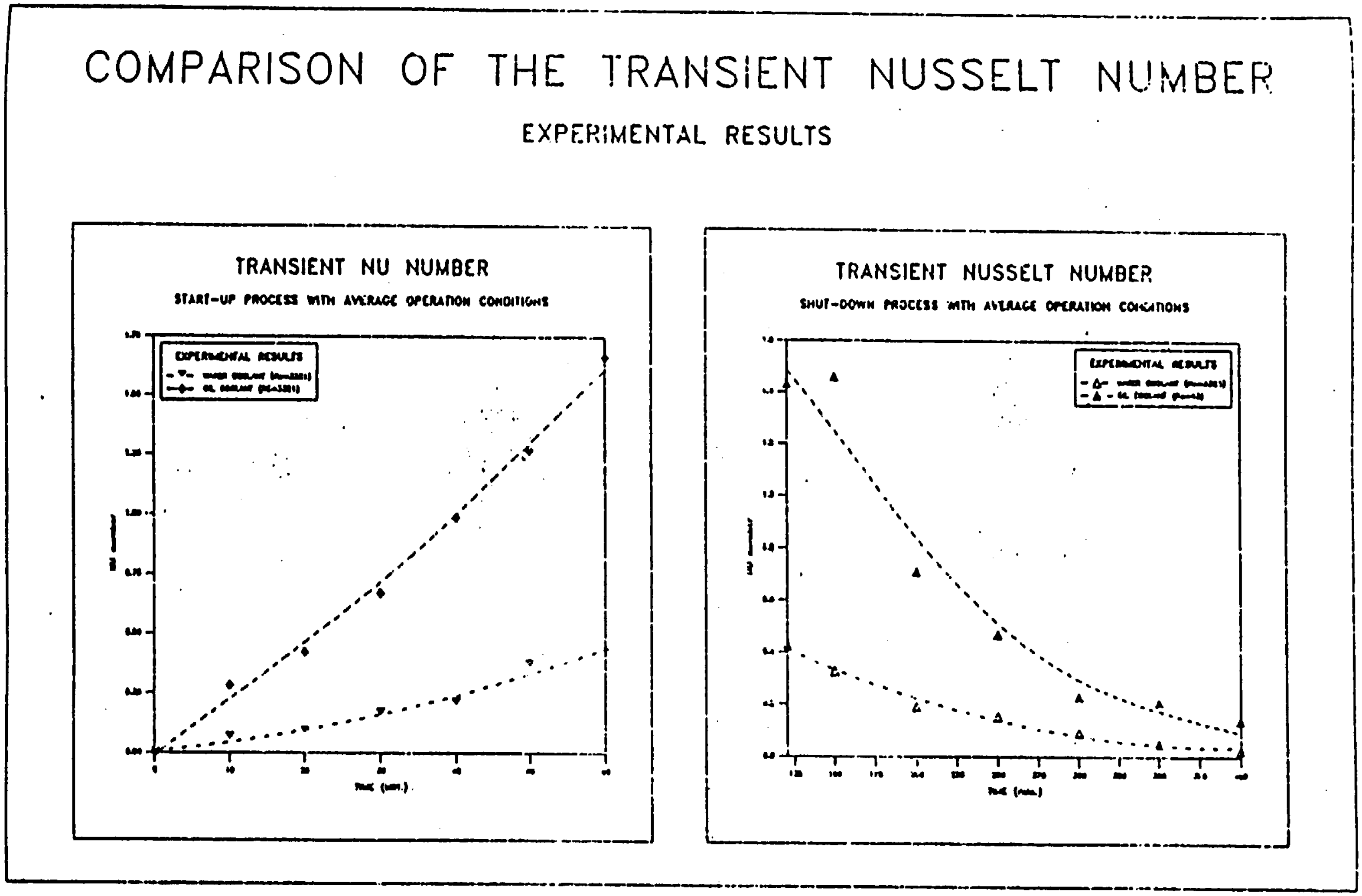


Figure 138. Comparisons of Experimental Nusselt Numbers.

coolant. Typically, as expected, the peak temperature areas were located in cell portions remote from the entrance side of the coolant during the start-up process. Considering the heat flux of the electrode, we notice that in general the heat flux is more uniform with higher stack pressure due to the homogeneous temperature distribution profiles of the electrode.

Considering the current density distribution, it is noticed that during the start-up process, the increase in the electrode temperature during the start-up process increased the fuel utilization rate and the chemical reaction between the reactants and consequently the production and travel of free electrons as demonstrated by the 2-D and 3-D contour profiles presented in Chapter VI. Also, the increase of the applied clamping pressure caused the electrode temperature to rise and that affected electron production rate while increasing the Re number will reduce the current density during a start-up process as shown in Figure 139. On the other hand, during the shut-down process three opposing factors were working against each other and affecting the transient current density distribution. The first factor, the thermal energy positive effect on the chemical reaction rate of the reactants, the second factor, effect of the temperature peak areas on the free electrons' travel ability and the third factor, the effect of the reduction of the fuel flow rate. Therefore, the effect of increasing the stack pressure and increasing the cooling

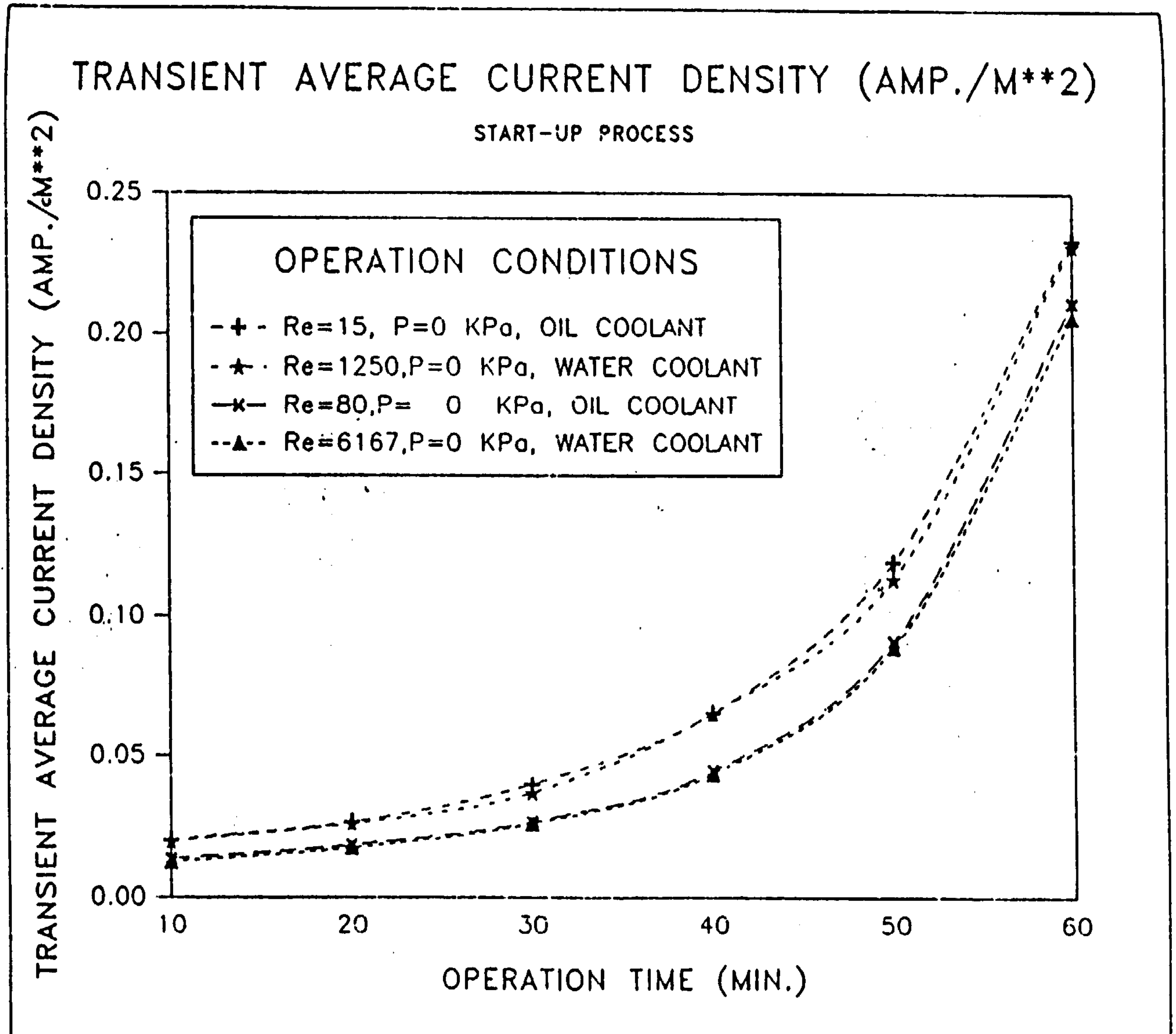


Figure 139. Transient Average Current Density (Start-Up).

fluid Re number and the fluid thermophysical properties effect could not be isolated, as shown in Chapter VI.

In comparing experimental results with results obtained analytically, the observed difference was found to be within acceptable range. Referring to Figure 140 we notice that differences between the reported experimental results and the analytical results of the transient overall heat transfer coefficient did not exceed the maximum of 8.25% and on the average the difference was 5.322% during the considered start-up and shut-down process for both coolant for the average operation condition, P = 1400 and Re = 3321 for water and Re=47 for oil. Also referring to Chapter V Figures we notice that the average deviation between the experimental and analytical transient average electrode temperature results was 6.351%.

By comparing the results of runs with identical conditions and considering the accuracy of the used equipment, the experimental results error should not exceed a maximum of 10%. The major source of errors in the experimental work, refer to Chapter III, can be summarized as follows.

(a) accuracy of the experimental instrumentation especially the thermocouples, flow meters and electrical power supply measurement equipment used.

(b) Cooling system configuration, the affect of this factor is important due to the fact that

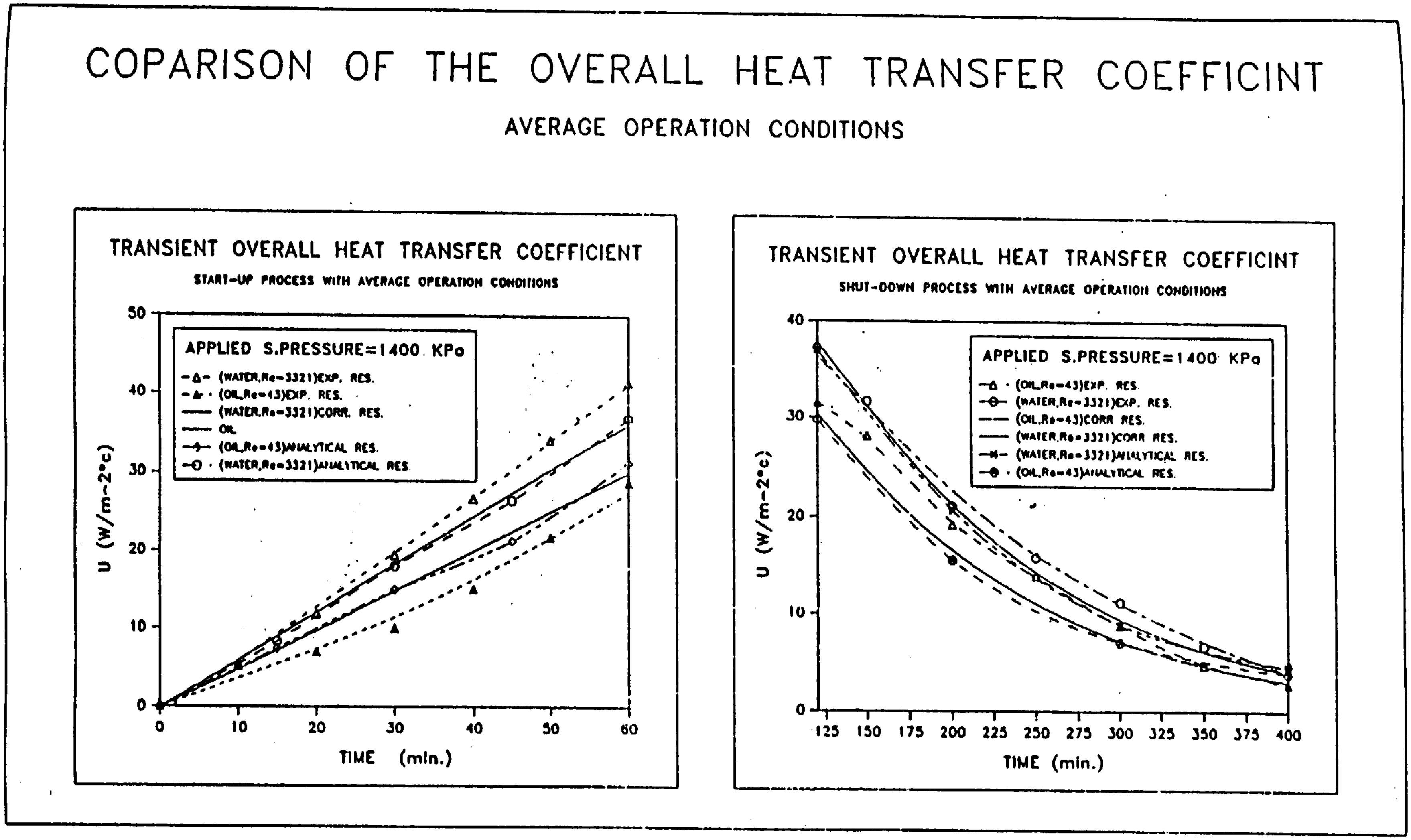


Figure 140. Comparisons of Experimental and Analytical U(t) Results.

the fitting of the serpentine cooling configurations and surface roughness of the internal areas of the tubes can cause turbulant flow and high pressure drop even with relatively low Re numbers. It was beyond the capability of the used instrumentation and scope of this study to determine how significant was the effect of such factor on the overall heat transfer coefficient. The observed influence of this factor on the accuracy of experimental results in similar experimental set-ups was mainly related to the relationship between convective heat transfer coefficient which is a function of the mixed bulk flow temperature ($T_m$) versus the friction coefficient which is a function of the mean flow velocity.

(c) Heat losses to the surrounding environment: Although additional insulation was used to reduce the heat transfer from the control volume, unavoided heat transfer by radiation and convection occurred during the lengthy experimental run time intervals.

(d) A correction factor was used when oil is used as a coolant to eliminate or reduce the error caused by the efficiency of the secondary cooling process for the closed cooling systems

that affected the temperature of the return coolant.

(e) The effect of two-phase flow when water was used as a coolant was a contributor in the marginal error of the experimental results. The cooling tube temperature exceeded 100°C during several runs and that can easily cause the generation of the gaseous phase at least in the case of water.

(f) Human error factor should also be taken into account inspite of the fact that most of the monitoring process was done automatically. However, the gradual variations of the power supplied to the cell plate was controlled manually and checked by a secondary set of amperage and voltage measuring instrumentations.

# CHAPTER VIII

# CONCLUSIONS AND RECOMMENDATIONS

## 8.1 Conclusions

The following can be concluded from the experimental investigation and the comparison with the theoretical results.

(a) The effects of the clamping stack pressure on the surpentine cooling system performance: increasing pressure on the PAFC system will increase the transient overall heat transfer coefficient and consequently the heat transfer to the cooling fluid and this in turn improves the efficiency of the cooling system, whether it is an open system or a closed system with a secondary cooling system. This effect is mainly due to the plastic deformation of the cooling plate and cell plate that will cause the increase of the common contact surface and reduce the thermal contact resistance significantly.

(b) The general transient performance of the serpentine cooling system: the transient performance of both experimental serpentine

cooling systems used can be described as reliable and effective provided that the electrode peak temperature is always kept below 210 degrees C to prevent any damages to thermocouples adhesive material or the resistive heating elements. This reasonably good performance is basically due to the fact that cooling fluids in their liquid phase have high heat capacity and can transfer additional thermal energy by means of the latent energy that is observed during the phase change process when pressurizing is not available as in the considered experimental setup. On the other hand, several serious problems were noticed with the use of such systems, which can be summarized as follows:

(a-1) Leaks from the cooling coil inside the control volume caused by corrosion, long fluid travel path inside the cooling coil, and high pressure difference through fittings. The cooling system leak can negatively influence the electrode chemical reaction and cause irreversible damages. But this risk can be reduced effectively by improving the cooling system design to reduce the number of fittings used and employing non corrosive materials with high thermal conductivity.

(1-2) Coolant effective contact area: This problem can be reduced by combining long travel paths with the flexibility of serpentine systems to be expanded on large cooling areas. But larger numbers of independent coils with shorter total travel distance should be used to compensate for reducing the tube diameters in order to maintain a reasonable pressure drop. This method will also improve the transient electrode temperature distribution uniformity.

(a-3) High initial cost and maintenance of the serpentine cooling systems: the high initial cost is usually due to the design complexity and the use of a non-corrosive tube material. The high maintenance cost is normally observed when a closed cooling system is used with a cooling tower as part of the cooling system.

(c) The transient current density distribution: Three factors will affect the transient current density profiles, the transient temperature distribution, the flow rate of the reactants and efficiency of the chemical reactions, and its relationship with the thermal energy. These factors will determine the phase density at a certain area.

(d) The accuracy of the modified computer code:

The comparison between the experimental and theoretical results generated by the modified computer code revealed a significant improvement in the accuracy of theoretical results because of the consideration of the effect of thermal contact resistance as a function of stack pressure and other important experimental conditions such as the return cooling fluid temperature.

## 8.2 Recommendations

In the light of the results obtained from the presented experimental and theoretical study, the following is recommended to enlarge the scope of the gained knowledge in this field for any further scientific work utilizing similar experimental methods or set-up:

(a) The effect of two-phase flow on the transient heat transfer should be recognized and studied carefully to modify the computer code to be sensible to that important factor.

(b) The effect of pressurizing the cooling system on the PAFC efficiency and cooling system performance should be studied carefully.

(c) The heat loss by radiation and convection can be reduced by containing the considered control volume in a sealed reflective space.

(d) The effect of the cooling tube roughness and the configuration on the cooling system performance, turbulant flow effect, and unaccounted for pressure drop, should be analyzed.

(e) More actual simulation of the temperature distribution can be created if the number of

resistive heating element coils is increased and their center location is shifted toward the fuel entrance side. This should be done in conjunction with the suggested cooling system modifications described in the previous section.

(f) The closed cooling system should be modified to provide higher oil volumetric flow rates than it is presently capable of, Re=15 to Re=80. This can be done by eliminating the flexible joints and fittings and increasing the horsepower of the circulating pump.

(g) The C.S.U. experimental set-up should be connected to the VAX computer center utilizing the 1200 BUAD rated modum available to facilitate the time consuming monitoring process and obtain more accurate results. This modification will allow efficient testing of the transient performance of other cooling systems such as the gasious straight channeling cooling system utilizing a variety of compressible fluids.

(h) The existing PAFC experimental models should be modified to use Hydrogen as a fuel and a cooling system, including a cooling tower, or an air condensor, and tested as a

practical co-generation prototype to reduce the KWH and KWD consumption that can be further developed for commercial applications such as hospitals and refrigeration warehouses.

(i) The effect of applying a perpendicular magnetic field on the cooling system's performance by influencing the flow and heat transfer characteristics of a magnetohydrodynamic, MHD, coolant such as hard and sea water is extremely important and should be tested for the considered PAFC model. Another advantage of using the magnetic will be to reduce the scaling factor which will consequently cause the increase of the thermal efficiency of the cooling system.

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# APPENDIX A-1

# WATER COOLANT

# HEAT TRANSFER CHARACTERISTICS

Start-Up Process: Table (A-1-1) - (A-1-2)

Shut-Down Process: Table (A-1-3) - (A-1-4)

RE = 15.00
PRESSURE (KPa)= 0
FLUID :WATER

| TIME | NU1 | U1 | % U1/V1 |
|---|---|---|---|
| 0.000E+00 | 0.000E+00 | 0.100E-09 | 0.100E+03 |
| 0.100E+01 | 0.336E-02 | 0.357E+00 | 0.100E+03 |
| 0.200E+01 | 0.674E-02 | 0.716E+00 | 0.100E+03 |
| 0.300E+01 | 0.102E-01 | 0.108E+01 | 0.100E+03 |
| 0.400E+01 | 0.136E-01 | 0.144E+01 | 0.100E+03 |
| 0.500E+01 | 0.171E-01 | 0.181E+01 | 0.100E+03 |
| 0.600E+01 | 0.206E-01 | 0.217E+01 | 0.999E+02 |
| 0.700E+01 | 0.241E-01 | 0.254E+01 | 0.999E+02 |
| 0.800E+01 | 0.276E-01 | 0.292E+01 | 0.999E+02 |
| 0.900E+01 | 0.312E-01 | 0.329E+01 | 0.999E+02 |
| 0.100E+02 | 0.348E-01 | 0.367E+01 | 0.998E+02 |
| 0.110E+02 | 0.385E-01 | 0.405E+01 | 0.998E+02 |
| 0.120E+02 | 0.422E-01 | 0.443E+01 | 0.998E+02 |
| 0.130E+02 | 0.459E-01 | 0.481E+01 | 0.997E+02 |
| 0.140E+02 | 0.496E-01 | 0.520E+01 | 0.997E+02 |
| 0.150E+02 | 0.534E-01 | 0.558E+01 | 0.996E+02 |
| 0.160E+02 | 0.572E-01 | 0.597E+01 | 0.996E+02 |
| 0.170E+02 | 0.610E-01 | 0.636E+01 | 0.995E+02 |
| 0.180E+02 | 0.649E-01 | 0.675E+01 | 0.994E+02 |
| 0.190E+02 | 0.687E-01 | 0.715E+01 | 0.994E+02 |
| 0.200E+02 | 0.727E-01 | 0.754E+01 | 0.993E+02 |
| 0.210E+02 | 0.766E-01 | 0.794E+01 | 0.992E+02 |
| 0.220E+02 | 0.806E-01 | 0.834E+01 | 0.991E+02 |
| 0.230E+02 | 0.846E-01 | 0.874E+01 | 0.990E+02 |
| 0.240E+02 | 0.887E-01 | 0.914E+01 | 0.989E+02 |
| 0.250E+02 | 0.928E-01 | 0.954E+01 | 0.988E+02 |
| 0.260E+02 | 0.969E-01 | 0.994E+01 | 0.987E+02 |
| 0.270E+02 | 0.101E+00 | 0.103E+02 | 0.986E+02 |
| 0.280E+02 | 0.105E+00 | 0.108E+02 | 0.985E+02 |
| 0.290E+02 | 0.109E+00 | 0.112E+02 | 0.984E+02 |
| 0.300E+02 | 0.114E+00 | 0.116E+02 | 0.982E+02 |
| 0.310E+02 | 0.118E+00 | 0.120E+02 | 0.981E+02 |
| 0.320E+02 | 0.122E+00 | 0.124E+02 | 0.980E+02 |
| 0.330E+02 | 0.127E+00 | 0.128E+02 | 0.978E+02 |
| 0.340E+02 | 0.131E+00 | 0.132E+02 | 0.977E+02 |
| 0.350E+02 | 0.136E+00 | 0.136E+02 | 0.975E+02 |
| 0.360E+02 | 0.140E+00 | 0.140E+02 | 0.974E+02 |
| 0.370E+02 | 0.145E+00 | 0.144E+02 | 0.972E+02 |
| 0.380E+02 | 0.149E+00 | 0.148E+02 | 0.970E+02 |
| 0.390E+02 | 0.154E+00 | 0.152E+02 | 0.968E+02 |
| 0.400E+02 | 0.158E+00 | 0.157E+02 | 0.966E+02 |
| 0.410E+02 | 0.163E+00 | 0.161E+02 | 0.964E+02 |
| 0.420E+02 | 0.168E+00 | 0.165E+02 | 0.962E+02 |
| 0.430E+02 | 0.172E+00 | 0.169E+02 | 0.960E+02 |
| 0.440E+02 | 0.177E+00 | 0.173E+02 | 0.958E+02 |
| 0.450E+02 | 0.182E+00 | 0.177E+02 | 0.956E+02 |
| 0.460E+02 | 0.187E+00 | 0.181E+02 | 0.953E+02 |
| 0.470E+02 | 0.192E+00 | 0.185E+02 | 0.951E+02 |
| 0.480E+02 | 0.197E+00 | 0.189E+02 | 0.949E+02 |
| 0.490E+02 | 0.202E+00 | 0.193E+02 | 0.946E+02 |
| 0.500E+02 | 0.207E+00 | 0.197E+02 | 0.943E+02 |
| 0.510E+02 | 0.212E+00 | 0.201E+02 | 0.941E+02 |
| 0.520E+02 | 0.217E+00 | 0.205E+02 | 0.938E+02 |
| 0.530E+02 | 0.222E+00 | 0.209E+02 | 0.935E+02 |
| 0.540E+02 | 0.227E+00 | 0.213E+02 | 0.932E+02 |
| 0.550E+02 | 0.232E+00 | 0.217E+02 | 0.929E+02 |
| 0.560E+02 | 0.238E+00 | 0.221E+02 | 0.926E+02 |
| 0.570E+02 | 0.243E+00 | 0.225E+02 | 0.923E+02 |
| 0.580E+02 | 0.248E+00 | 0.228E+02 | 0.920E+02 |
| 0.590E+02 | 0.254E+00 | 0.232E+02 | 0.917E+02 |

Table A-1-1. Heat Transfer Characteristics During Start-Up Process (Water Coolant, P=0 KPa, Re=15).

RE = 15.00
PRESSURE (KPa)= 3500.
FLUID :WATER

| TIME | NU5 | U5 | % U5/V5 |
|---|---|---|---|
| 0.000E+00 | 0.000E+00 | 0.100E-09 | 0.100E+03 |
| 0.100E+01 | 0.517E-02 | 0.549E+00 | 0.100E+03 |
| 0.200E+01 | 0.104E-01 | 0.110E+01 | 0.100E+03 |
| 0.300E+01 | 0.156E-01 | 0.166E+01 | 0.100E+03 |
| 0.400E+01 | 0.209E-01 | 0.221E+01 | 0.100E+03 |
| 0.500E+01 | 0.263E-01 | 0.277E+01 | 0.100E+03 |
| 0.600E+01 | 0.317E-01 | 0.334E+01 | 0.100E+03 |
| 0.700E+01 | 0.371E-01 | 0.390E+01 | 0.999E+02 |
| 0.800E+01 | 0.426E-01 | 0.447E+01 | 0.999E+02 |
| 0.900E+01 | 0.481E-01 | 0.504E+01 | 0.999E+02 |
| 0.100E+02 | 0.537E-01 | 0.561E+01 | 0.999E+02 |
| 0.110E+02 | 0.593E-01 | 0.619E+01 | 0.999E+02 |
| 0.120E+02 | 0.650E-01 | 0.677E+01 | 0.998E+02 |
| 0.130E+02 | 0.707E-01 | 0.735E+01 | 0.998E+02 |
| 0.140E+02 | 0.764E-01 | 0.793E+01 | 0.998E+02 |
| 0.150E+02 | 0.822E-01 | 0.851E+01 | 0.997E+02 |
| 0.160E+02 | 0.881E-01 | 0.910E+01 | 0.997E+02 |
| 0.170E+02 | 0.940E-01 | 0.969E+01 | 0.997E+02 |
| 0.180E+02 | 0.999E-01 | 0.103E+02 | 0.996E+02 |
| 0.190E+02 | 0.106E+00 | 0.109E+02 | 0.996E+02 |
| 0.200E+02 | 0.112E+00 | 0.115E+02 | 0.995E+02 |
| 0.210E+02 | 0.118E+00 | 0.121E+02 | 0.995E+02 |
| 0.220E+02 | 0.124E+00 | 0.127E+02 | 0.994E+02 |
| 0.230E+02 | 0.130E+00 | 0.133E+02 | 0.994E+02 |
| 0.240E+02 | 0.137E+00 | 0.139E+02 | 0.993E+02 |
| 0.250E+02 | 0.143E+00 | 0.145E+02 | 0.992E+02 |
| 0.260E+02 | 0.149E+00 | 0.151E+02 | 0.992E+02 |
| 0.270E+02 | 0.156E+00 | 0.157E+02 | 0.991E+02 |
| 0.280E+02 | 0.162E+00 | 0.163E+02 | 0.990E+02 |
| 0.290E+02 | 0.169E+00 | 0.169E+02 | 0.989E+02 |
| 0.300E+02 | 0.175E+00 | 0.175E+02 | 0.988E+02 |
| 0.310E+02 | 0.182E+00 | 0.181E+02 | 0.987E+02 |
| 0.320E+02 | 0.189E+00 | 0.187E+02 | 0.987E+02 |
| 0.330E+02 | 0.195E+00 | 0.193E+02 | 0.986E+02 |
| 0.340E+02 | 0.202E+00 | 0.199E+02 | 0.985E+02 |
| 0.350E+02 | 0.209E+00 | 0.205E+02 | 0.984E+02 |
| 0.360E+02 | 0.216E+00 | 0.212E+02 | 0.982E+02 |
| 0.370E+02 | 0.223E+00 | 0.218E+02 | 0.981E+02 |
| 0.380E+02 | 0.230E+00 | 0.224E+02 | 0.980E+02 |
| 0.390E+02 | 0.237E+00 | 0.230E+02 | 0.979E+02 |
| 0.400E+02 | 0.244E+00 | 0.236E+02 | 0.978E+02 |
| 0.410E+02 | 0.251E+00 | 0.242E+02 | 0.976E+02 |
| 0.420E+02 | 0.258E+00 | 0.248E+02 | 0.975E+02 |
| 0.430E+02 | 0.266E+00 | 0.254E+02 | 0.974E+02 |
| 0.440E+02 | 0.273E+00 | 0.260E+02 | 0.972E+02 |
| 0.450E+02 | 0.281E+00 | 0.266E+02 | 0.971E+02 |
| 0.460E+02 | 0.288E+00 | 0.273E+02 | 0.969E+02 |
| 0.470E+02 | 0.296E+00 | 0.279E+02 | 0.968E+02 |
| 0.480E+02 | 0.303E+00 | 0.285E+02 | 0.966E+02 |
| 0.490E+02 | 0.311E+00 | 0.291E+02 | 0.964E+02 |
| 0.500E+02 | 0.319E+00 | 0.297E+02 | 0.963E+02 |
| 0.510E+02 | 0.326E+00 | 0.303E+02 | 0.961E+02 |
| 0.520E+02 | 0.334E+00 | 0.309E+02 | 0.959E+02 |
| 0.530E+02 | 0.342E+00 | 0.315E+02 | 0.957E+02 |
| 0.540E+02 | 0.350E+00 | 0.321E+02 | 0.955E+02 |
| 0.550E+02 | 0.358E+00 | 0.327E+02 | 0.953E+02 |
| 0.560E+02 | 0.366E+00 | 0.332E+02 | 0.951E+02 |
| 0.570E+02 | 0.375E+00 | 0.338E+02 | 0.949E+02 |
| 0.580E+02 | 0.383E+00 | 0.344E+02 | 0.947E+02 |
| 0.590E+02 | 0.391E+00 | 0.350E+02 | 0.945E+02 |

TABLE A-1-2.

Heat Transfer Characteristics During Start-Up Process (Water Coolant, P=3500 KPa Re=15).

RE = 15.00
PRESSURE (KPa)= 0
FLUID :WATER

| TIME | NU1 | U1 | % U1/V1 |
|---|---|---|---|
| 0.120E+03 | 0.336E+00 | 0.249E+02 | 0.915E+02 |
| 0.125E+03 | 0.318E+00 | 0.240E+02 | 0.919E+02 |
| 0.130E+03 | 0.302E+00 | 0.232E+02 | 0.924E+02 |
| 0.135E+03 | 0.286E+00 | 0.224E+02 | 0.928E+02 |
| 0.140E+03 | 0.271E+00 | 0.216E+02 | 0.932E+02 |
| 0.145E+03 | 0.256E+00 | 0.208E+02 | 0.935E+02 |
| 0.150E+03 | 0.243E+00 | 0.200E+02 | 0.939E+02 |
| 0.155E+03 | 0.230E+00 | 0.193E+02 | 0.942E+02 |
| 0.160E+03 | 0.218E+00 | 0.186E+02 | 0.945E+02 |
| 0.165E+03 | 0.206E+00 | 0.179E+02 | 0.949E+02 |
| 0.170E+03 | 0.196E+00 | 0.172E+02 | 0.951E+02 |
| 0.175E+03 | 0.185E+00 | 0.166E+02 | 0.954E+02 |
| 0.180E+03 | 0.175E+00 | 0.159E+02 | 0.957E+02 |
| 0.185E+03 | 0.166E+00 | 0.153E+02 | 0.959E+02 |
| 0.190E+03 | 0.157E+00 | 0.147E+02 | 0.962E+02 |
| 0.195E+03 | 0.149E+00 | 0.141E+02 | 0.964E+02 |
| 0.200E+03 | 0.141E+00 | 0.136E+02 | 0.966E+02 |
| 0.205E+03 | 0.134E+00 | 0.131E+02 | 0.968E+02 |
| 0.210E+03 | 0.127E+00 | 0.125E+02 | 0.970E+02 |
| 0.215E+03 | 0.120E+00 | 0.120E+02 | 0.971E+02 |
| 0.220E+03 | 0.114E+00 | 0.116E+02 | 0.973E+02 |
| 0.225E+03 | 0.108E+00 | 0.111E+02 | 0.975E+02 |
| 0.230E+03 | 0.102E+00 | 0.106E+02 | 0.976E+02 |
| 0.235E+03 | 0.967E-01 | 0.102E+02 | 0.978E+02 |
| 0.240E+03 | 0.917E-01 | 0.980E+01 | 0.979E+02 |
| 0.245E+03 | 0.868E-01 | 0.940E+01 | 0.980E+02 |
| 0.250E+03 | 0.822E-01 | 0.902E+01 | 0.981E+02 |
| 0.255E+03 | 0.779E-01 | 0.865E+01 | 0.982E+02 |
| 0.260E+03 | 0.738E-01 | 0.829E+01 | 0.984E+02 |
| 0.265E+03 | 0.699E-01 | 0.795E+01 | 0.985E+02 |
| 0.270E+03 | 0.662E-01 | 0.762E+01 | 0.985E+02 |
| 0.275E+03 | 0.627E-01 | 0.730E+01 | 0.986E+02 |
| 0.280E+03 | 0.594E-01 | 0.700E+01 | 0.987E+02 |
| 0.285E+03 | 0.563E-01 | 0.671E+01 | 0.988E+02 |
| 0.290E+03 | 0.533E-01 | 0.643E+01 | 0.989E+02 |
| 0.295E+03 | 0.505E-01 | 0.616E+01 | 0.989E+02 |
| 0.300E+03 | 0.479E-01 | 0.590E+01 | 0.990E+02 |
| 0.305E+03 | 0.453E-01 | 0.565E+01 | 0.991E+02 |
| 0.310E+03 | 0.430E-01 | 0.541E+01 | 0.991E+02 |
| 0.315E+03 | 0.407E-01 | 0.518E+01 | 0.992E+02 |
| 0.320E+03 | 0.385E-01 | 0.497E+01 | 0.992E+02 |
| 0.325E+03 | 0.365E-01 | 0.476E+01 | 0.993E+02 |
| 0.330E+03 | 0.346E-01 | 0.455E+01 | 0.993E+02 |
| 0.335E+03 | 0.328E-01 | 0.436E+01 | 0.994E+02 |
| 0.340E+03 | 0.310E-01 | 0.418E+01 | 0.994E+02 |
| 0.345E+03 | 0.294E-01 | 0.400E+01 | 0.994E+02 |
| 0.350E+03 | 0.279E-01 | 0.383E+01 | 0.995E+02 |
| 0.355E+03 | 0.264E-01 | 0.366E+01 | 0.995E+02 |
| 0.360E+03 | 0.250E-01 | 0.351E+01 | 0.995E+02 |
| 0.365E+03 | 0.237E-01 | 0.336E+01 | 0.996E+02 |
| 0.370E+03 | 0.224E-01 | 0.321E+01 | 0.996E+02 |
| 0.375E+03 | 0.213E-01 | 0.308E+01 | 0.996E+02 |
| 0.380E+03 | 0.201E-01 | 0.294E+01 | 0.996E+02 |
| 0.385E+03 | 0.191E-01 | 0.282E+01 | 0.997E+02 |
| 0.390E+03 | 0.181E-01 | 0.270E+01 | 0.997E+02 |
| 0.395E+03 | 0.171E-01 | 0.258E+01 | 0.997E+02 |
| 0.400E+03 | 0.162E-01 | 0.247E+01 | 0.997E+02 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

TABLE A-1-3.

Heat Transfer Characteristics During Shut-Down Process (Water Coolant, P=0 KPa, Re=15).

RE = 15.00
PRESSURE (KPa)= 3500.
FLUID :WATER

| TIME | NUS | US | % US/VS |
|---|---|---|---|
| 0.120E+03 | 0.567E+00 | 0.375E+02 | 0.944E+02 |
| 0.125E+03 | 0.537E+00 | 0.362E+02 | 0.947E+02 |
| 0.130E+03 | 0.508E+00 | 0.349E+02 | 0.949E+02 |
| 0.135E+03 | 0.482E+00 | 0.337E+02 | 0.952E+02 |
| 0.140E+03 | 0.456E+00 | 0.325E+02 | 0.955E+02 |
| 0.145E+03 | 0.432E+00 | 0.314E+02 | 0.957E+02 |
| 0.150E+03 | 0.409E+00 | 0.302E+02 | 0.960E+02 |
| 0.155E+03 | 0.388E+00 | 0.291E+02 | 0.962E+02 |
| 0.160E+03 | 0.367E+00 | 0.281E+02 | 0.964E+02 |
| 0.165E+03 | 0.348E+00 | 0.270E+02 | 0.966E+02 |
| 0.170E+03 | 0.330E+00 | 0.260E+02 | 0.968E+02 |
| 0.175E+03 | 0.312E+00 | 0.250E+02 | 0.970E+02 |
| 0.180E+03 | 0.296E+00 | 0.241E+02 | 0.971E+02 |
| 0.185E+03 | 0.280E+00 | 0.232E+02 | 0.973E+02 |
| 0.190E+03 | 0.266E+00 | 0.223E+02 | 0.974E+02 |
| 0.195E+03 | 0.252E+00 | 0.214E+02 | 0.976E+02 |
| 0.200E+03 | 0.238E+00 | 0.206E+02 | 0.977E+02 |
| 0.205E+03 | 0.226E+00 | 0.198E+02 | 0.979E+02 |
| 0.210E+03 | 0.214E+00 | 0.190E+02 | 0.980E+02 |
| 0.215E+03 | 0.203E+00 | 0.183E+02 | 0.981E+02 |
| 0.220E+03 | 0.192E+00 | 0.176E+02 | 0.982E+02 |
| 0.225E+03 | 0.182E+00 | 0.169E+02 | 0.983E+02 |
| 0.230E+03 | 0.172E+00 | 0.162E+02 | 0.984E+02 |
| 0.235E+03 | 0.163E+00 | 0.155E+02 | 0.985E+02 |
| 0.240E+03 | 0.155E+00 | 0.149E+02 | 0.986E+02 |
| 0.245E+03 | 0.146E+00 | 0.143E+02 | 0.987E+02 |
| 0.250E+03 | 0.139E+00 | 0.137E+02 | 0.988E+02 |
| 0.255E+03 | 0.131E+00 | 0.132E+02 | 0.988E+02 |
| 0.260E+03 | 0.124E+00 | 0.126E+02 | 0.989E+02 |
| 0.265E+03 | 0.118E+00 | 0.121E+02 | 0.990E+02 |
| 0.270E+03 | 0.112E+00 | 0.116E+02 | 0.990E+02 |
| 0.275E+03 | 0.106E+00 | 0.111E+02 | 0.991E+02 |
| 0.280E+03 | 0.100E+00 | 0.107E+02 | 0.991E+02 |
| 0.285E+03 | 0.949E-01 | 0.102E+02 | 0.992E+02 |
| 0.290E+03 | 0.899E-01 | 0.981E+01 | 0.992E+02 |
| 0.295E+03 | 0.852E-01 | 0.940E+01 | 0.993E+02 |
| 0.300E+03 | 0.807E-01 | 0.901E+01 | 0.993E+02 |
| 0.305E+03 | 0.764E-01 | 0.864E+01 | 0.994E+02 |
| 0.310E+03 | 0.724E-01 | 0.827E+01 | 0.994E+02 |
| 0.315E+03 | 0.686E-01 | 0.793E+01 | 0.994E+02 |
| 0.320E+03 | 0.650E-01 | 0.759E+01 | 0.995E+02 |
| 0.325E+03 | 0.616E-01 | 0.728E+01 | 0.995E+02 |
| 0.330E+03 | 0.583E-01 | 0.697E+01 | 0.995E+02 |
| 0.335E+03 | 0.552E-01 | 0.667E+01 | 0.996E+02 |
| 0.340E+03 | 0.523E-01 | 0.639E+01 | 0.996E+02 |
| 0.345E+03 | 0.496E-01 | 0.612E+01 | 0.996E+02 |
| 0.350E+03 | 0.470E-01 | 0.586E+01 | 0.996E+02 |
| 0.355E+03 | 0.445E-01 | 0.561E+01 | 0.997E+02 |
| 0.360E+03 | 0.421E-01 | 0.538E+01 | 0.997E+02 |
| 0.365E+03 | 0.399E-01 | 0.515E+01 | 0.997E+02 |
| 0.370E+03 | 0.378E-01 | 0.493E+01 | 0.997E+02 |
| 0.375E+03 | 0.358E-01 | 0.472E+01 | 0.997E+02 |
| 0.380E+03 | 0.339E-01 | 0.452E+01 | 0.998E+02 |
| 0.385E+03 | 0.322E-01 | 0.432E+01 | 0.998E+02 |
| 0.390E+03 | 0.305E-01 | 0.414E+01 | 0.998E+02 |
| 0.395E+03 | 0.289E-01 | 0.396E+01 | 0.998E+02 |
| 0.400E+03 | 0.273E-01 | 0.379E+01 | 0.998E+02 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

TABLE A-1-4.

Heat Transfer Characteristics During Shut-Down Process (Water Coolant, P=3500 KPa, Re=15).

# APPENDIX A-2

## WATER COOLANT

## THERMAL CONTACT RESISTANCE AND AFFECTIVE TEMPERATURE DROP

Start-Up Process: Table (A-2-1) - (A-2-2)

Shut-Down Process: Table (A-2-3) - (A-2-4)

RE = 15.
PRESSURE (KPa)= 0
FLUID :WATER

| TIME | D1 | R1 |
|---|---|---|
| ---- | -- | -- |
| 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.100E+01 | 0.989E-01 | 0.423E-04 |
| 0.200E+01 | 0.199E+00 | 0.852E-04 |
| 0.300E+01 | 0.300E+00 | 0.129E-03 |
| 0.400E+01 | 0.403E+00 | 0.172E-03 |
| 0.500E+01 | 0.507E+00 | 0.217E-03 |
| 0.600E+01 | 0.612E+00 | 0.262E-03 |
| 0.700E+01 | 0.719E+00 | 0.307E-03 |
| 0.800E+01 | 0.826E+00 | 0.353E-03 |
| 0.900E+01 | 0.936E+00 | 0.400E-03 |
| 0.100E+02 | 0.105E+01 | 0.447E-03 |
| 0.110E+02 | 0.116E+01 | 0.494E-03 |
| 0.120E+02 | 0.127E+01 | 0.543E-03 |
| 0.130E+02 | 0.139E+01 | 0.591E-03 |
| 0.140E+02 | 0.150E+01 | 0.641E-03 |
| 0.150E+02 | 0.162E+01 | 0.691E-03 |
| 0.160E+02 | 0.174E+01 | 0.741E-03 |
| 0.170E+02 | 0.186E+01 | 0.792E-03 |
| 0.180E+02 | 0.198E+01 | 0.844E-03 |
| 0.190E+02 | 0.210E+01 | 0.897E-03 |
| 0.200E+02 | 0.223E+01 | 0.950E-03 |
| 0.210E+02 | 0.236E+01 | 0.100E-02 |
| 0.220E+02 | 0.248E+01 | 0.106E-02 |
| 0.230E+02 | 0.261E+01 | 0.111E-02 |
| 0.240E+02 | 0.274E+01 | 0.117E-02 |
| 0.250E+02 | 0.288E+01 | 0.122E-02 |
| 0.260E+02 | 0.301E+01 | 0.128E-02 |
| 0.270E+02 | 0.315E+01 | 0.134E-02 |
| 0.280E+02 | 0.329E+01 | 0.140E-02 |
| 0.290E+02 | 0.343E+01 | 0.146E-02 |
| 0.300E+02 | 0.357E+01 | 0.152E-02 |
| 0.310E+02 | 0.371E+01 | 0.158E-02 |
| 0.320E+02 | 0.386E+01 | 0.164E-02 |
| 0.330E+02 | 0.400E+01 | 0.170E-02 |
| 0.340E+02 | 0.415E+01 | 0.176E-02 |
| 0.350E+02 | 0.430E+01 | 0.182E-02 |
| 0.360E+02 | 0.445E+01 | 0.189E-02 |
| 0.370E+02 | 0.461E+01 | 0.195E-02 |
| 0.380E+02 | 0.476E+01 | 0.202E-02 |
| 0.390E+02 | 0.492E+01 | 0.208E-02 |
| 0.400E+02 | 0.508E+01 | 0.215E-02 |
| 0.410E+02 | 0.524E+01 | 0.222E-02 |
| 0.420E+02 | 0.541E+01 | 0.229E-02 |
| 0.430E+02 | 0.557E+01 | 0.236E-02 |
| 0.440E+02 | 0.574E+01 | 0.243E-02 |
| 0.450E+02 | 0.591E+01 | 0.250E-02 |
| 0.460E+02 | 0.608E+01 | 0.257E-02 |
| 0.470E+02 | 0.626E+01 | 0.264E-02 |
| 0.480E+02 | 0.643E+01 | 0.272E-02 |
| 0.490E+02 | 0.661E+01 | 0.279E-02 |
| 0.500E+02 | 0.679E+01 | 0.287E-02 |
| 0.510E+02 | 0.698E+01 | 0.294E-02 |
| 0.520E+02 | 0.716E+01 | 0.302E-02 |
| 0.530E+02 | 0.735E+01 | 0.310E-02 |
| 0.540E+02 | 0.754E+01 | 0.318E-02 |
| 0.550E+02 | 0.773E+01 | 0.326E-02 |
| 0.560E+02 | 0.792E+01 | 0.334E-02 |
| 0.570E+02 | 0.812E+01 | 0.342E-02 |
| 0.580E+02 | 0.832E+01 | 0.350E-02 |
| 0.590E+02 | 0.852E+01 | 0.359E-02 |

TABLE A-2-1.

Effective Temperature Drop and Thermal Contact Resistance During Start-Up Process (Water Collant, P=0 KPa, Re=15).

RE = 15.
PRESSURE (KPa)= 3500.
FLUID :WATER

| TIME | D5 | R5 |
|---|---|---|
| 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.100E+01 | 0.573E-01 | 0.186E-04 |
| 0.200E+01 | 0.115E+00 | 0.374E-04 |
| 0.300E+01 | 0.174E+00 | 0.564E-04 |
| 0.400E+01 | 0.234E+00 | 0.756E-04 |
| 0.500E+01 | 0.294E+00 | 0.951E-04 |
| 0.600E+01 | 0.355E+00 | 0.115E-03 |
| 0.700E+01 | 0.416E+00 | 0.135E-03 |
| 0.800E+01 | 0.479E+00 | 0.155E-03 |
| 0.900E+01 | 0.542E+00 | 0.175E-03 |
| 0.100E+02 | 0.606E+00 | 0.196E-03 |
| 0.110E+02 | 0.671E+00 | 0.217E-03 |
| 0.120E+02 | 0.736E+00 | 0.238E-03 |
| 0.130E+02 | 0.803E+00 | 0.259E-03 |
| 0.140E+02 | 0.870E+00 | 0.281E-03 |
| 0.150E+02 | 0.938E+00 | 0.303E-03 |
| 0.160E+02 | 0.101E+01 | 0.325E-03 |
| 0.170E+02 | 0.108E+01 | 0.347E-03 |
| 0.180E+02 | 0.115E+01 | 0.370E-03 |
| 0.190E+02 | 0.122E+01 | 0.393E-03 |
| 0.200E+02 | 0.129E+01 | 0.416E-03 |
| 0.210E+02 | 0.136E+01 | 0.440E-03 |
| 0.220E+02 | 0.144E+01 | 0.464E-03 |
| 0.230E+02 | 0.151E+01 | 0.488E-03 |
| 0.240E+02 | 0.159E+01 | 0.512E-03 |
| 0.250E+02 | 0.167E+01 | 0.537E-03 |
| 0.260E+02 | 0.175E+01 | 0.562E-03 |
| 0.270E+02 | 0.182E+01 | 0.587E-03 |
| 0.280E+02 | 0.190E+01 | 0.612E-03 |
| 0.290E+02 | 0.198E+01 | 0.638E-03 |
| 0.300E+02 | 0.207E+01 | 0.664E-03 |
| 0.310E+02 | 0.215E+01 | 0.691E-03 |
| 0.320E+02 | 0.223E+01 | 0.717E-03 |
| 0.330E+02 | 0.232E+01 | 0.745E-03 |
| 0.340E+02 | 0.240E+01 | 0.772E-03 |
| 0.350E+02 | 0.249E+01 | 0.800E-03 |
| 0.360E+02 | 0.258E+01 | 0.828E-03 |
| 0.370E+02 | 0.267E+01 | 0.856E-03 |
| 0.380E+02 | 0.276E+01 | 0.885E-03 |
| 0.390E+02 | 0.285E+01 | 0.914E-03 |
| 0.400E+02 | 0.294E+01 | 0.943E-03 |
| 0.410E+02 | 0.304E+01 | 0.973E-03 |
| 0.420E+02 | 0.313E+01 | 0.100E-02 |
| 0.430E+02 | 0.323E+01 | 0.103E-02 |
| 0.440E+02 | 0.333E+01 | 0.106E-02 |
| 0.450E+02 | 0.342E+01 | 0.110E-02 |
| 0.460E+02 | 0.352E+01 | 0.113E-02 |
| 0.470E+02 | 0.362E+01 | 0.116E-02 |
| 0.480E+02 | 0.373E+01 | 0.119E-02 |
| 0.490E+02 | 0.383E+01 | 0.122E-02 |
| 0.500E+02 | 0.394E+01 | 0.126E-02 |
| 0.510E+02 | 0.404E+01 | 0.129E-02 |
| 0.520E+02 | 0.415E+01 | 0.132E-02 |
| 0.530E+02 | 0.426E+01 | 0.136E-02 |
| 0.540E+02 | 0.437E+01 | 0.139E-02 |
| 0.550E+02 | 0.448E+01 | 0.143E-02 |
| 0.560E+02 | 0.459E+01 | 0.146E-02 |
| 0.570E+02 | 0.471E+01 | 0.150E-02 |
| 0.580E+02 | 0.482E+01 | 0.154E-02 |
| 0.590E+02 | 0.494E+01 | 0.157E-02 |

TABLE A-2-2.

Effective Temperature Drop and Thermal Contact Resistance During Start-Up Process (Water Coolant, P=3500 KPa, Re=15).

RE = 15.
PRESSURE (KPa)= 0.
FLUID :WATER

| TIME | D1 | R1 |
|---|---|---|
| 0.120E+03 | 0.867E+01 | 0.360E-02 |
| 0.125E+03 | 0.848E+01 | 0.353E-02 |
| 0.130E+03 | 0.829E+01 | 0.346E-02 |
| 0.135E+03 | 0.810E+01 | 0.339E-02 |
| 0.140E+03 | 0.792E+01 | 0.333E-02 |
| 0.145E+03 | 0.774E+01 | 0.326E-02 |
| 0.150E+03 | 0.756E+01 | 0.320E-02 |
| 0.155E+03 | 0.739E+01 | 0.314E-02 |
| 0.160E+03 | 0.723E+01 | 0.308E-02 |
| 0.165E+03 | 0.706E+01 | 0.302E-02 |
| 0.170E+03 | 0.690E+01 | 0.296E-02 |
| 0.175E+03 | 0.675E+01 | 0.290E-02 |
| 0.180E+03 | 0.660E+01 | 0.285E-02 |
| 0.185E+03 | 0.645E+01 | 0.279E-02 |
| 0.190E+03 | 0.630E+01 | 0.274E-02 |
| 0.195E+03 | 0.616E+01 | 0.269E-02 |
| 0.200E+03 | 0.602E+01 | 0.263E-02 |
| 0.205E+03 | 0.589E+01 | 0.258E-02 |
| 0.210E+03 | 0.575E+01 | 0.253E-02 |
| 0.215E+03 | 0.562E+01 | 0.248E-02 |
| 0.220E+03 | 0.550E+01 | 0.244E-02 |
| 0.225E+03 | 0.537E+01 | 0.239E-02 |
| 0.230E+03 | 0.525E+01 | 0.234E-02 |
| 0.235E+03 | 0.513E+01 | 0.230E-02 |
| 0.240E+03 | 0.502E+01 | 0.225E-02 |
| 0.245E+03 | 0.491E+01 | 0.221E-02 |
| 0.250E+03 | 0.480E+01 | 0.217E-02 |
| 0.255E+03 | 0.469E+01 | 0.212E-02 |
| 0.260E+03 | 0.458E+01 | 0.208E-02 |
| 0.265E+03 | 0.448E+01 | 0.204E-02 |
| 0.270E+03 | 0.438E+01 | 0.200E-02 |
| 0.275E+03 | 0.428E+01 | 0.196E-02 |
| 0.280E+03 | 0.418E+01 | 0.193E-02 |
| 0.285E+03 | 0.409E+01 | 0.189E-02 |
| 0.290E+03 | 0.400E+01 | 0.185E-02 |
| 0.295E+03 | 0.391E+01 | 0.182E-02 |
| 0.300E+03 | 0.382E+01 | 0.178E-02 |
| 0.305E+03 | 0.373E+01 | 0.175E-02 |
| 0.310E+03 | 0.365E+01 | 0.171E-02 |
| 0.315E+03 | 0.357E+01 | 0.168E-02 |
| 0.320E+03 | 0.349E+01 | 0.165E-02 |
| 0.325E+03 | 0.341E+01 | 0.162E-02 |
| 0.330E+03 | 0.333E+01 | 0.158E-02 |
| 0.335E+03 | 0.326E+01 | 0.155E-02 |
| 0.340E+03 | 0.318E+01 | 0.152E-02 |
| 0.345E+03 | 0.311E+01 | 0.149E-02 |
| 0.350E+03 | 0.304E+01 | 0.147E-02 |
| 0.355E+03 | 0.297E+01 | 0.144E-02 |
| 0.360E+03 | 0.290E+01 | 0.141E-02 |
| 0.365E+03 | 0.284E+01 | 0.138E-02 |
| 0.370E+03 | 0.278E+01 | 0.136E-02 |
| 0.375E+03 | 0.271E+01 | 0.133E-02 |
| 0.380E+03 | 0.265E+01 | 0.130E-02 |
| 0.385E+03 | 0.259E+01 | 0.128E-02 |
| 0.390E+03 | 0.253E+01 | 0.125E-02 |
| 0.395E+03 | 0.248E+01 | 0.123E-02 |
| 0.400E+03 | 0.242E+01 | 0.121E-02 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 |

TABLE A-2-3.

Effective Temperature Drop and Thermal Contact Resistance During Shut-Down Process (Water Coolant, P=0 KPa, Re=15).

RE = 15.
PRESSURE (KPa)= 3500
FLUID :WATER

| TIME | D5 | R5 |
|---|---|---|
| 0.120E+03 | 0.673E+01 | 0.158E-02 |
| 0.125E+03 | 0.658E+01 | 0.155E-02 |
| 0.130E+03 | 0.643E+01 | 0.152E-02 |
| 0.135E+03 | 0.628E+01 | 0.149E-02 |
| 0.140E+03 | 0.614E+01 | 0.146E-02 |
| 0.145E+03 | 0.600E+01 | 0.143E-02 |
| 0.150E+03 | 0.587E+01 | 0.140E-02 |
| 0.155E+03 | 0.574E+01 | 0.138E-02 |
| 0.160E+03 | 0.561E+01 | 0.135E-02 |
| 0.165E+03 | 0.548E+01 | 0.132E-02 |
| 0.170E+03 | 0.536E+01 | 0.130E-02 |
| 0.175E+03 | 0.524E+01 | 0.127E-02 |
| 0.180E+03 | 0.512E+01 | 0.125E-02 |
| 0.185E+03 | 0.500E+01 | 0.122E-02 |
| 0.190E+03 | 0.489E+01 | 0.120E-02 |
| 0.195E+03 | 0.478E+01 | 0.118E-02 |
| 0.200E+03 | 0.467E+01 | 0.115E-02 |
| 0.205E+03 | 0.457E+01 | 0.113E-02 |
| 0.210E+03 | 0.446E+01 | 0.111E-02 |
| 0.215E+03 | 0.436E+01 | 0.109E-02 |
| 0.220E+03 | 0.427E+01 | 0.107E-02 |
| 0.225E+03 | 0.417E+01 | 0.105E-02 |
| 0.230E+03 | 0.408E+01 | 0.103E-02 |
| 0.235E+03 | 0.398E+01 | 0.101E-02 |
| 0.240E+03 | 0.389E+01 | 0.988E-03 |
| 0.245E+03 | 0.381E+01 | 0.968E-03 |
| 0.250E+03 | 0.372E+01 | 0.950E-03 |
| 0.255E+03 | 0.364E+01 | 0.931E-03 |
| 0.260E+03 | 0.355E+01 | 0.913E-03 |
| 0.265E+03 | 0.347E+01 | 0.896E-03 |
| 0.270E+03 | 0.340E+01 | 0.878E-03 |
| 0.275E+03 | 0.332E+01 | 0.861E-03 |
| 0.280E+03 | 0.324E+01 | 0.845E-03 |
| 0.285E+03 | 0.317E+01 | 0.828E-03 |
| 0.290E+03 | 0.310E+01 | 0.812E-03 |
| 0.295E+03 | 0.303E+01 | 0.797E-03 |
| 0.300E+03 | 0.296E+01 | 0.781E-03 |
| 0.305E+03 | 0.290E+01 | 0.766E-03 |
| 0.310E+03 | 0.283E+01 | 0.751E-03 |
| 0.315E+03 | 0.277E+01 | 0.737E-03 |
| 0.320E+03 | 0.270E+01 | 0.723E-03 |
| 0.325E+03 | 0.264E+01 | 0.709E-03 |
| 0.330E+03 | 0.258E+01 | 0.695E-03 |
| 0.335E+03 | 0.253E+01 | 0.681E-03 |
| 0.340E+03 | 0.247E+01 | 0.668E-03 |
| 0.345E+03 | 0.241E+01 | 0.655E-03 |
| 0.350E+03 | 0.236E+01 | 0.643E-03 |
| 0.355E+03 | 0.231E+01 | 0.630E-03 |
| 0.360E+03 | 0.225E+01 | 0.618E-03 |
| 0.365E+03 | 0.220E+01 | 0.606E-03 |
| 0.370E+03 | 0.215E+01 | 0.594E-03 |
| 0.375E+03 | 0.210E+01 | 0.583E-03 |
| 0.380E+03 | 0.206E+01 | 0.572E-03 |
| 0.385E+03 | 0.201E+01 | 0.561E-03 |
| 0.390E+03 | 0.197E+01 | 0.550E-03 |
| 0.395E+03 | 0.192E+01 | 0.539E-03 |
| 0.400E+03 | 0.188E+01 | 0.529E-03 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 |

TABLE A-2-4.

Effective Temperature Drop and Thermal Contact Resistance During Shut-Down Process (Water Coolant, P=3500 KPa, Re=15).

# APPENDIX B-1

# OIL COOLANT

# HEAT TRANSFER CHARACTERISTICS

Start-Up Process: Table (B-1-1) - (B-1-2)

Shut-Down Process: Table (B-1-3) - (B-1-4)

RE = 1250.00
PRESSURE (KPa)= 0.
FLUID :OIL

| TIME | NU1 | U1 | % U1/V1 |
|---|---|---|---|
| 0.000E+00 | 0.000E+00 | 0.100E-09 | 0.100E+03 |
| 0.100E+01 | 0.305E-01 | 0.750E+00 | 0.100E+03 |
| 0.200E+01 | 0.612E-01 | 0.150E+01 | 0.100E+03 |
| 0.300E+01 | 0.922E-01 | 0.226E+01 | 0.100E+03 |
| 0.400E+01 | 0.124E+00 | 0.302E+01 | 0.999E+02 |
| 0.500E+01 | 0.155E+00 | 0.378E+01 | 0.999E+02 |
| 0.600E+01 | 0.187E+00 | 0.454E+01 | 0.999E+02 |
| 0.700E+01 | 0.219E+00 | 0.530E+01 | 0.998E+02 |
| 0.800E+01 | 0.251E+00 | 0.607E+01 | 0.998E+02 |
| 0.900E+01 | 0.284E+00 | 0.683E+01 | 0.997E+02 |
| 0.100E+02 | 0.317E+00 | 0.760E+01 | 0.997E+02 |
| 0.110E+02 | 0.350E+00 | 0.837E+01 | 0.996E+02 |
| 0.120E+02 | 0.384E+00 | 0.914E+01 | 0.995E+02 |
| 0.130E+02 | 0.418E+00 | 0.991E+01 | 0.994E+02 |
| 0.140E+02 | 0.452E+00 | 0.107E+02 | 0.993E+02 |
| 0.150E+02 | 0.487E+00 | 0.114E+02 | 0.992E+02 |
| 0.160E+02 | 0.521E+00 | 0.122E+02 | 0.991E+02 |
| 0.170E+02 | 0.556E+00 | 0.130E+02 | 0.990E+02 |
| 0.180E+02 | 0.592E+00 | 0.137E+02 | 0.988E+02 |
| 0.190E+02 | 0.628E+00 | 0.145E+02 | 0.987E+02 |
| 0.200E+02 | 0.664E+00 | 0.153E+02 | 0.985E+02 |
| 0.210E+02 | 0.700E+00 | 0.160E+02 | 0.984E+02 |
| 0.220E+02 | 0.737E+00 | 0.168E+02 | 0.982E+02 |
| 0.230E+02 | 0.774E+00 | 0.176E+02 | 0.980E+02 |
| 0.240E+02 | 0.811E+00 | 0.183E+02 | 0.978E+02 |
| 0.250E+02 | 0.849E+00 | 0.191E+02 | 0.976E+02 |
| 0.260E+02 | 0.887E+00 | 0.198E+02 | 0.974E+02 |
| 0.270E+02 | 0.925E+00 | 0.206E+02 | 0.972E+02 |
| 0.280E+02 | 0.964E+00 | 0.213E+02 | 0.970E+02 |
| 0.290E+02 | 0.100E+01 | 0.221E+02 | 0.967E+02 |
| 0.300E+02 | 0.104E+01 | 0.228E+02 | 0.965E+02 |
| 0.310E+02 | 0.108E+01 | 0.235E+02 | 0.962E+02 |
| 0.320E+02 | 0.112E+01 | 0.242E+02 | 0.960E+02 |
| 0.330E+02 | 0.116E+01 | 0.250E+02 | 0.957E+02 |
| 0.340E+02 | 0.120E+01 | 0.257E+02 | 0.954E+02 |
| 0.350E+02 | 0.124E+01 | 0.264E+02 | 0.951E+02 |
| 0.360E+02 | 0.129E+01 | 0.271E+02 | 0.948E+02 |
| 0.370E+02 | 0.133E+01 | 0.278E+02 | 0.945E+02 |
| 0.380E+02 | 0.137E+01 | 0.285E+02 | 0.941E+02 |
| 0.390E+02 | 0.141E+01 | 0.292E+02 | 0.938E+02 |
| 0.400E+02 | 0.146E+01 | 0.298E+02 | 0.935E+02 |
| 0.410E+02 | 0.150E+01 | 0.305E+02 | 0.931E+02 |
| 0.420E+02 | 0.154E+01 | 0.312E+02 | 0.927E+02 |
| 0.430E+02 | 0.159E+01 | 0.318E+02 | 0.923E+02 |
| 0.440E+02 | 0.163E+01 | 0.325E+02 | 0.920E+02 |
| 0.450E+02 | 0.168E+01 | 0.331E+02 | 0.916E+02 |
| 0.460E+02 | 0.172E+01 | 0.337E+02 | 0.911E+02 |
| 0.470E+02 | 0.177E+01 | 0.344E+02 | 0.907E+02 |
| 0.480E+02 | 0.181E+01 | 0.350E+02 | 0.903E+02 |
| 0.490E+02 | 0.186E+01 | 0.356E+02 | 0.899E+02 |
| 0.500E+02 | 0.191E+01 | 0.361E+02 | 0.894E+02 |
| 0.510E+02 | 0.195E+01 | 0.367E+02 | 0.890E+02 |
| 0.520E+02 | 0.200E+01 | 0.373E+02 | 0.885E+02 |
| 0.530E+02 | 0.205E+01 | 0.378E+02 | 0.880E+02 |
| 0.540E+02 | 0.210E+01 | 0.384E+02 | 0.875E+02 |
| 0.550E+02 | 0.215E+01 | 0.389E+02 | 0.870E+02 |
| 0.560E+02 | 0.220E+01 | 0.394E+02 | 0.865E+02 |
| 0.570E+02 | 0.225E+01 | 0.400E+02 | 0.860E+02 |
| 0.580E+02 | 0.230E+01 | 0.405E+02 | 0.855E+02 |
| 0.590E+02 | 0.235E+01 | 0.409E+02 | 0.850E+02 |

TABLE B-1-1.

Heat Transfer Characteristics During Start-Up Process (Oil Coolant, P=0 KPa, Re=1250).

RE = 1250.00
PRESSURE (KPa)= 3500.
FLUID :OIL

| TIME | NU5 | U5 | % U5/V5 |
|---|---|---|---|
| 0.000E+00 | 0.000E+00 | 0.100E-09 | 0.100E+03 |
| 0.100E+01 | 0.490E-01 | 0.120E+01 | 0.100E+03 |
| 0.200E+01 | 0.984E-01 | 0.241E+01 | 0.100E+03 |
| 0.300E+01 | 0.148E+00 | 0.361E+01 | 0.100E+03 |
| 0.400E+01 | 0.199E+00 | 0.481E+01 | 0.100E+03 |
| 0.500E+01 | 0.249E+00 | 0.602E+01 | 0.999E+02 |
| 0.600E+01 | 0.300E+00 | 0.722E+01 | 0.999E+02 |
| 0.700E+01 | 0.352E+00 | 0.842E+01 | 0.999E+02 |
| 0.800E+01 | 0.404E+00 | 0.962E+01 | 0.998E+02 |
| 0.900E+01 | 0.457E+00 | 0.108E+02 | 0.998E+02 |
| 0.100E+02 | 0.510E+00 | 0.120E+02 | 0.998E+02 |
| 0.110E+02 | 0.563E+00 | 0.132E+02 | 0.997E+02 |
| 0.120E+02 | 0.617E+00 | 0.144E+02 | 0.997E+02 |
| 0.130E+02 | 0.672E+00 | 0.156E+02 | 0.996E+02 |
| 0.140E+02 | 0.727E+00 | 0.168E+02 | 0.995E+02 |
| 0.150E+02 | 0.782E+00 | 0.179E+02 | 0.994E+02 |
| 0.160E+02 | 0.838E+00 | 0.191E+02 | 0.994E+02 |
| 0.170E+02 | 0.894E+00 | 0.203E+02 | 0.993E+02 |
| 0.180E+02 | 0.951E+00 | 0.215E+02 | 0.992E+02 |
| 0.190E+02 | 0.101E+01 | 0.226E+02 | 0.991E+02 |
| 0.200E+02 | 0.107E+01 | 0.238E+02 | 0.990E+02 |
| 0.210E+02 | 0.113E+01 | 0.250E+02 | 0.989E+02 |
| 0.220E+02 | 0.118E+01 | 0.261E+02 | 0.988E+02 |
| 0.230E+02 | 0.124E+01 | 0.272E+02 | 0.987E+02 |
| 0.240E+02 | 0.130E+01 | 0.284E+02 | 0.985E+02 |
| 0.250E+02 | 0.136E+01 | 0.295E+02 | 0.984E+02 |
| 0.260E+02 | 0.143E+01 | 0.306E+02 | 0.983E+02 |
| 0.270E+02 | 0.149E+01 | 0.318E+02 | 0.981E+02 |
| 0.280E+02 | 0.155E+01 | 0.329E+02 | 0.980E+02 |
| 0.290E+02 | 0.161E+01 | 0.340E+02 | 0.978E+02 |
| 0.300E+02 | 0.167E+01 | 0.351E+02 | 0.976E+02 |
| 0.310E+02 | 0.174E+01 | 0.362E+02 | 0.975E+02 |
| 0.320E+02 | 0.180E+01 | 0.373E+02 | 0.973E+02 |
| 0.330E+02 | 0.187E+01 | 0.383E+02 | 0.971E+02 |
| 0.340E+02 | 0.193E+01 | 0.394E+02 | 0.969E+02 |
| 0.350E+02 | 0.200E+01 | 0.405E+02 | 0.967E+02 |
| 0.360E+02 | 0.207E+01 | 0.415E+02 | 0.965E+02 |
| 0.370E+02 | 0.213E+01 | 0.425E+02 | 0.963E+02 |
| 0.380E+02 | 0.220E+01 | 0.436E+02 | 0.961E+02 |
| 0.390E+02 | 0.227E+01 | 0.446E+02 | 0.958E+02 |
| 0.400E+02 | 0.234E+01 | 0.456E+02 | 0.956E+02 |
| 0.410E+02 | 0.241E+01 | 0.466E+02 | 0.954E+02 |
| 0.420E+02 | 0.248E+01 | 0.476E+02 | 0.951E+02 |
| 0.430E+02 | 0.255E+01 | 0.486E+02 | 0.949E+02 |
| 0.440E+02 | 0.262E+01 | 0.495E+02 | 0.946E+02 |
| 0.450E+02 | 0.269E+01 | 0.505E+02 | 0.944E+02 |
| 0.460E+02 | 0.277E+01 | 0.514E+02 | 0.941E+02 |
| 0.470E+02 | 0.284E+01 | 0.524E+02 | 0.938E+02 |
| 0.480E+02 | 0.291E+01 | 0.533E+02 | 0.935E+02 |
| 0.490E+02 | 0.299E+01 | 0.542E+02 | 0.932E+02 |
| 0.500E+02 | 0.306E+01 | 0.551E+02 | 0.929E+02 |
| 0.510E+02 | 0.314E+01 | 0.559E+02 | 0.926E+02 |
| 0.520E+02 | 0.322E+01 | 0.568E+02 | 0.923E+02 |
| 0.530E+02 | 0.329E+01 | 0.577E+02 | 0.920E+02 |
| 0.540E+02 | 0.337E+01 | 0.585E+02 | 0.917E+02 |
| 0.550E+02 | 0.345E+01 | 0.593E+02 | 0.913E+02 |
| 0.560E+02 | 0.353E+01 | 0.601E+02 | 0.910E+02 |
| 0.570E+02 | 0.361E+01 | 0.609E+02 | 0.906E+02 |
| 0.580E+02 | 0.369E+01 | 0.617E+02 | 0.903E+02 |
| 0.590E+02 | 0.377E+01 | 0.625E+02 | 0.899E+02 |

TABLE B-1-2.

Heat Transfer Characteristics During Start-Up Process (Oil Coolant, P=3500 KPa, Re=1250).

RE = 1250.00
PRESSURE (KPa)= 0.
FLUID :OIL

| TIME | NU1 | U1 | % U1/V1 |
|---|---|---|---|
| 0.120E+03 | 0.961E+00 | 0.421E+02 | 0.850E+02 |
| 0.125E+03 | 0.910E+00 | 0.409E+02 | 0.856E+02 |
| 0.130E+03 | 0.862E+00 | 0.397E+02 | 0.863E+02 |
| 0.135E+03 | 0.817E+00 | 0.386E+02 | 0.869E+02 |
| 0.140E+03 | 0.774E+00 | 0.374E+02 | 0.875E+02 |
| 0.145E+03 | 0.733E+00 | 0.363E+02 | 0.881E+02 |
| 0.150E+03 | 0.694E+00 | 0.352E+02 | 0.887E+02 |
| 0.155E+03 | 0.658E+00 | 0.341E+02 | 0.892E+02 |
| 0.160E+03 | 0.623E+00 | 0.330E+02 | 0.897E+02 |
| 0.165E+03 | 0.590E+00 | 0.319E+02 | 0.902E+02 |
| 0.170E+03 | 0.559E+00 | 0.308E+02 | 0.907E+02 |
| 0.175E+03 | 0.530E+00 | 0.298E+02 | 0.912E+02 |
| 0.180E+03 | 0.502E+00 | 0.288E+02 | 0.916E+02 |
| 0.185E+03 | 0.475E+00 | 0.278E+02 | 0.920E+02 |
| 0.190E+03 | 0.450E+00 | 0.269E+02 | 0.924E+02 |
| 0.195E+03 | 0.427E+00 | 0.259E+02 | 0.928E+02 |
| 0.200E+03 | 0.404E+00 | 0.250E+02 | 0.932E+02 |
| 0.205E+03 | 0.383E+00 | 0.241E+02 | 0.935E+02 |
| 0.210E+03 | 0.363E+00 | 0.232E+02 | 0.939E+02 |
| 0.215E+03 | 0.344E+00 | 0.224E+02 | 0.942E+02 |
| 0.220E+03 | 0.325E+00 | 0.216E+02 | 0.945E+02 |
| 0.225E+03 | 0.308E+00 | 0.208E+02 | 0.948E+02 |
| 0.230E+03 | 0.292E+00 | 0.200E+02 | 0.951E+02 |
| 0.235E+03 | 0.277E+00 | 0.193E+02 | 0.953E+02 |
| 0.240E+03 | 0.262E+00 | 0.185E+02 | 0.956E+02 |
| 0.245E+03 | 0.248E+00 | 0.178E+02 | 0.958E+02 |
| 0.250E+03 | 0.235E+00 | 0.171E+02 | 0.961E+02 |
| 0.255E+03 | 0.223E+00 | 0.165E+02 | 0.963E+02 |
| 0.260E+03 | 0.211E+00 | 0.158E+02 | 0.965E+02 |
| 0.265E+03 | 0.200E+00 | 0.152E+02 | 0.967E+02 |
| 0.270E+03 | 0.189E+00 | 0.146E+02 | 0.969E+02 |
| 0.275E+03 | 0.179E+00 | 0.140E+02 | 0.970E+02 |
| 0.280E+03 | 0.170E+00 | 0.135E+02 | 0.972E+02 |
| 0.285E+03 | 0.161E+00 | 0.129E+02 | 0.974E+02 |
| 0.290E+03 | 0.153E+00 | 0.124E+02 | 0.975E+02 |
| 0.295E+03 | 0.145E+00 | 0.119E+02 | 0.976E+02 |
| 0.300E+03 | 0.137E+00 | 0.114E+02 | 0.978E+02 |
| 0.305E+03 | 0.130E+00 | 0.110E+02 | 0.979E+02 |
| 0.310E+03 | 0.123E+00 | 0.105E+02 | 0.980E+02 |
| 0.315E+03 | 0.116E+00 | 0.101E+02 | 0.981E+02 |
| 0.320E+03 | 0.110E+00 | 0.969E+01 | 0.982E+02 |
| 0.325E+03 | 0.104E+00 | 0.930E+01 | 0.983E+02 |
| 0.330E+03 | 0.989E-01 | 0.891E+01 | 0.984E+02 |
| 0.335E+03 | 0.937E-01 | 0.855E+01 | 0.985E+02 |
| 0.340E+03 | 0.888E-01 | 0.819E+01 | 0.986E+02 |
| 0.345E+03 | 0.841E-01 | 0.785E+01 | 0.987E+02 |
| 0.350E+03 | 0.797E-01 | 0.753E+01 | 0.988E+02 |
| 0.355E+03 | 0.755E-01 | 0.721E+01 | 0.988E+02 |
| 0.360E+03 | 0.715E-01 | 0.691E+01 | 0.989E+02 |
| 0.365E+03 | 0.677E-01 | 0.662E+01 | 0.990E+02 |
| 0.370E+03 | 0.642E-01 | 0.634E+01 | 0.990E+02 |
| 0.375E+03 | 0.608E-01 | 0.608E+01 | 0.991E+02 |
| 0.380E+03 | 0.576E-01 | 0.582E+01 | 0.991E+02 |
| 0.385E+03 | 0.545E-01 | 0.558E+01 | 0.992E+02 |
| 0.390E+03 | 0.517E-01 | 0.534E+01 | 0.992E+02 |
| 0.395E+03 | 0.489E-01 | 0.511E+01 | 0.993E+02 |
| 0.400E+03 | 0.464E-01 | 0.490E+01 | 0.993E+02 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

TABLE B-1-3.

Heat Transfer Characteristics During Shut-Down Process (Oil Coolant, P=0 KPa, Re=1250).

RE = 1250.00
PRESSURE (KPa)= 3500.
FLUID :OIL

| TIME | NUS | US | % US/VS |
|---|---|---|---|
| 0.120E+03 | 0.219E+01 | 0.651E+02 | 0.901E+02 |
| 0.125E+03 | 0.208E+01 | 0.633E+02 | 0.905E+02 |
| 0.130E+03 | 0.197E+01 | 0.615E+02 | 0.909E+02 |
| 0.135E+03 | 0.186E+01 | 0.598E+02 | 0.913E+02 |
| 0.140E+03 | 0.176E+01 | 0.580E+02 | 0.917E+02 |
| 0.145E+03 | 0.167E+01 | 0.563E+02 | 0.921E+02 |
| 0.150E+03 | 0.158E+01 | 0.546E+02 | 0.925E+02 |
| 0.155E+03 | 0.150E+01 | 0.530E+02 | 0.928E+02 |
| 0.160E+03 | 0.142E+01 | 0.513E+02 | 0.932E+02 |
| 0.165E+03 | 0.135E+01 | 0.497E+02 | 0.935E+02 |
| 0.170E+03 | 0.128E+01 | 0.481E+02 | 0.938E+02 |
| 0.175E+03 | 0.121E+01 | 0.465E+02 | 0.941E+02 |
| 0.180E+03 | 0.114E+01 | 0.450E+02 | 0.944E+02 |
| 0.185E+03 | 0.108E+01 | 0.435E+02 | 0.947E+02 |
| 0.190E+03 | 0.103E+01 | 0.421E+02 | 0.949E+02 |
| 0.195E+03 | 0.973E+00 | 0.406E+02 | 0.952E+02 |
| 0.200E+03 | 0.922E+00 | 0.392E+02 | 0.954E+02 |
| 0.205E+03 | 0.873E+00 | 0.379E+02 | 0.957E+02 |
| 0.210E+03 | 0.827E+00 | 0.365E+02 | 0.959E+02 |
| 0.215E+03 | 0.783E+00 | 0.353E+02 | 0.961E+02 |
| 0.220E+03 | 0.742E+00 | 0.340E+02 | 0.963E+02 |
| 0.225E+03 | 0.703E+00 | 0.328E+02 | 0.965E+02 |
| 0.230E+03 | 0.666E+00 | 0.316E+02 | 0.967E+02 |
| 0.235E+03 | 0.631E+00 | 0.304E+02 | 0.969E+02 |
| 0.240E+03 | 0.598E+00 | 0.293E+02 | 0.970E+02 |
| 0.245E+03 | 0.566E+00 | 0.282E+02 | 0.972E+02 |
| 0.250E+03 | 0.536E+00 | 0.271E+02 | 0.973E+02 |
| 0.255E+03 | 0.508E+00 | 0.261E+02 | 0.975E+02 |
| 0.260E+03 | 0.481E+00 | 0.251E+02 | 0.976E+02 |
| 0.265E+03 | 0.456E+00 | 0.242E+02 | 0.977E+02 |
| 0.270E+03 | 0.432E+00 | 0.232E+02 | 0.979E+02 |
| 0.275E+03 | 0.409E+00 | 0.223E+02 | 0.980E+02 |
| 0.280E+03 | 0.388E+00 | 0.215E+02 | 0.981E+02 |
| 0.285E+03 | 0.367E+00 | 0.206E+02 | 0.982E+02 |
| 0.290E+03 | 0.348E+00 | 0.198E+02 | 0.983E+02 |
| 0.295E+03 | 0.329E+00 | 0.190E+02 | 0.984E+02 |
| 0.300E+03 | 0.312E+00 | 0.183E+02 | 0.985E+02 |
| 0.305E+03 | 0.296E+00 | 0.176E+02 | 0.986E+02 |
| 0.310E+03 | 0.280E+00 | 0.168E+02 | 0.986E+02 |
| 0.315E+03 | 0.265E+00 | 0.162E+02 | 0.987E+02 |
| 0.320E+03 | 0.251E+00 | 0.155E+02 | 0.988E+02 |
| 0.325E+03 | 0.238E+00 | 0.149E+02 | 0.989E+02 |
| 0.330E+03 | 0.226E+00 | 0.143E+02 | 0.989E+02 |
| 0.335E+03 | 0.214E+00 | 0.137E+02 | 0.990E+02 |
| 0.340E+03 | 0.202E+00 | 0.131E+02 | 0.990E+02 |
| 0.345E+03 | 0.192E+00 | 0.126E+02 | 0.991E+02 |
| 0.350E+03 | 0.182E+00 | 0.121E+02 | 0.992E+02 |
| 0.355E+03 | 0.172E+00 | 0.116E+02 | 0.992E+02 |
| 0.360E+03 | 0.163E+00 | 0.111E+02 | 0.992E+02 |
| 0.365E+03 | 0.154E+00 | 0.107E+02 | 0.993E+02 |
| 0.370E+03 | 0.146E+00 | 0.102E+02 | 0.993E+02 |
| 0.375E+03 | 0.139E+00 | 0.979E+01 | 0.994E+02 |
| 0.380E+03 | 0.131E+00 | 0.938E+01 | 0.994E+02 |
| 0.385E+03 | 0.124E+00 | 0.899E+01 | 0.994E+02 |
| 0.390E+03 | 0.118E+00 | 0.861E+01 | 0.995E+02 |
| 0.395E+03 | 0.112E+00 | 0.825E+01 | 0.995E+02 |
| 0.400E+03 | 0.106E+00 | 0.790E+01 | 0.995E+02 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

TABLE B-1-4.

Heat Transfer Characteristics During Shut-Down Process (Oil Coolant, P=3500 KPa, Re=1250).

# APPENDIX B-2

# OIL COOLANT

# THERMAL CONTACT RESISTANCE AND AFFECTIVE TEMPERATURE DROP

Start-Up Process: Table (B-2-1) - (B-2-2)

Shut-Down Process: Table (B-2-3) - (B-2-4)

RE = 1250.
PRESSURE (KPa)= 0.
FLUID :OIL

| TIME | D1 | R1 |
|---|---|---|
| 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.100E+01 | 0.966E-01 | 0.428E-04 |
| 0.200E+01 | 0.194E+00 | 0.861E-04 |
| 0.300E+01 | 0.293E+00 | 0.130E-03 |
| 0.400E+01 | 0.394E+00 | 0.174E-03 |
| 0.500E+01 | 0.495E+00 | 0.219E-03 |
| 0.600E+01 | 0.598E+00 | 0.265E-03 |
| 0.700E+01 | 0.702E+00 | 0.311E-03 |
| 0.800E+01 | 0.807E+00 | 0.358E-03 |
| 0.900E+01 | 0.914E+00 | 0.405E-03 |
| 0.100E+02 | 0.102E+01 | 0.452E-03 |
| 0.110E+02 | 0.113E+01 | 0.501E-03 |
| 0.120E+02 | 0.124E+01 | 0.550E-03 |
| 0.130E+02 | 0.135E+01 | 0.599E-03 |
| 0.140E+02 | 0.147E+01 | 0.650E-03 |
| 0.150E+02 | 0.158E+01 | 0.700E-03 |
| 0.160E+02 | 0.170E+01 | 0.752E-03 |
| 0.170E+02 | 0.181E+01 | 0.804E-03 |
| 0.180E+02 | 0.193E+01 | 0.856E-03 |
| 0.190E+02 | 0.205E+01 | 0.910E-03 |
| 0.200E+02 | 0.218E+01 | 0.964E-03 |
| 0.210E+02 | 0.230E+01 | 0.102E-02 |
| 0.220E+02 | 0.242E+01 | 0.107E-02 |
| 0.230E+02 | 0.255E+01 | 0.113E-02 |
| 0.240E+02 | 0.268E+01 | 0.119E-02 |
| 0.250E+02 | 0.281E+01 | 0.124E-02 |
| 0.260E+02 | 0.294E+01 | 0.130E-02 |
| 0.270E+02 | 0.307E+01 | 0.136E-02 |
| 0.280E+02 | 0.321E+01 | 0.142E-02 |
| 0.290E+02 | 0.334E+01 | 0.148E-02 |
| 0.300E+02 | 0.348E+01 | 0.154E-02 |
| 0.310E+02 | 0.362E+01 | 0.160E-02 |
| 0.320E+02 | 0.376E+01 | 0.167E-02 |
| 0.330E+02 | 0.390E+01 | 0.173E-02 |
| 0.340E+02 | 0.405E+01 | 0.179E-02 |
| 0.350E+02 | 0.419E+01 | 0.186E-02 |
| 0.360E+02 | 0.434E+01 | 0.192E-02 |
| 0.370E+02 | 0.449E+01 | 0.199E-02 |
| 0.380E+02 | 0.464E+01 | 0.206E-02 |
| 0.390E+02 | 0.480E+01 | 0.212E-02 |
| 0.400E+02 | 0.495E+01 | 0.219E-02 |
| 0.410E+02 | 0.511E+01 | 0.226E-02 |
| 0.420E+02 | 0.527E+01 | 0.233E-02 |
| 0.430E+02 | 0.543E+01 | 0.240E-02 |
| 0.440E+02 | 0.559E+01 | 0.248E-02 |
| 0.450E+02 | 0.576E+01 | 0.255E-02 |
| 0.460E+02 | 0.593E+01 | 0.262E-02 |
| 0.470E+02 | 0.609E+01 | 0.270E-02 |
| 0.480E+02 | 0.627E+01 | 0.278E-02 |
| 0.490E+02 | 0.644E+01 | 0.285E-02 |
| 0.500E+02 | 0.662E+01 | 0.293E-02 |
| 0.510E+02 | 0.679E+01 | 0.301E-02 |
| 0.520E+02 | 0.697E+01 | 0.309E-02 |
| 0.530E+02 | 0.716E+01 | 0.317E-02 |
| 0.540E+02 | 0.734E+01 | 0.325E-02 |
| 0.550E+02 | 0.753E+01 | 0.333E-02 |
| 0.560E+02 | 0.772E+01 | 0.342E-02 |
| 0.570E+02 | 0.791E+01 | 0.350E-02 |
| 0.580E+02 | 0.810E+01 | 0.359E-02 |
| 0.590E+02 | 0.830E+01 | 0.367E-02 |

TABLE B-2-1.

Effective Temperature Drop and Thermal Contact Resistance During Start-Up Process (Oil Coolant, P=0 KPa, Re=1250).

RE = 1250.
PRESSURE (KPa)= 3500.
FLUID :OIL

| TIME | DS | RS |
|---|---|---|
| 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.100E+01 | 0.560E-01 | 0.188E-04 |
| 0.200E+01 | 0.113E+00 | 0.378E-04 |
| 0.300E+01 | 0.170E+00 | 0.570E-04 |
| 0.400E+01 | 0.228E+00 | 0.765E-04 |
| 0.500E+01 | 0.287E+00 | 0.962E-04 |
| 0.600E+01 | 0.346E+00 | 0.116E-03 |
| 0.700E+01 | 0.407E+00 | 0.136E-03 |
| 0.800E+01 | 0.468E+00 | 0.157E-03 |
| 0.900E+01 | 0.529E+00 | 0.177E-03 |
| 0.100E+02 | 0.592E+00 | 0.198E-03 |
| 0.110E+02 | 0.655E+00 | 0.220E-03 |
| 0.120E+02 | 0.719E+00 | 0.241E-03 |
| 0.130E+02 | 0.784E+00 | 0.263E-03 |
| 0.140E+02 | 0.849E+00 | 0.285E-03 |
| 0.150E+02 | 0.916E+00 | 0.307E-03 |
| 0.160E+02 | 0.983E+00 | 0.330E-03 |
| 0.170E+02 | 0.105E+01 | 0.352E-03 |
| 0.180E+02 | 0.112E+01 | 0.375E-03 |
| 0.190E+02 | 0.119E+01 | 0.399E-03 |
| 0.200E+02 | 0.126E+01 | 0.422E-03 |
| 0.210E+02 | 0.133E+01 | 0.446E-03 |
| 0.220E+02 | 0.140E+01 | 0.471E-03 |
| 0.230E+02 | 0.148E+01 | 0.495E-03 |
| 0.240E+02 | 0.155E+01 | 0.520E-03 |
| 0.250E+02 | 0.163E+01 | 0.545E-03 |
| 0.260E+02 | 0.170E+01 | 0.571E-03 |
| 0.270E+02 | 0.178E+01 | 0.596E-03 |
| 0.280E+02 | 0.186E+01 | 0.622E-03 |
| 0.290E+02 | 0.194E+01 | 0.649E-03 |
| 0.300E+02 | 0.202E+01 | 0.676E-03 |
| 0.310E+02 | 0.210E+01 | 0.703E-03 |
| 0.320E+02 | 0.218E+01 | 0.730E-03 |
| 0.330E+02 | 0.226E+01 | 0.758E-03 |
| 0.340E+02 | 0.234E+01 | 0.786E-03 |
| 0.350E+02 | 0.243E+01 | 0.814E-03 |
| 0.360E+02 | 0.252E+01 | 0.843E-03 |
| 0.370E+02 | 0.260E+01 | 0.872E-03 |
| 0.380E+02 | 0.269E+01 | 0.902E-03 |
| 0.390E+02 | 0.278E+01 | 0.931E-03 |
| 0.400E+02 | 0.287E+01 | 0.962E-03 |
| 0.410E+02 | 0.296E+01 | 0.992E-03 |
| 0.420E+02 | 0.305E+01 | 0.102E-02 |
| 0.430E+02 | 0.315E+01 | 0.105E-02 |
| 0.440E+02 | 0.324E+01 | 0.109E-02 |
| 0.450E+02 | 0.334E+01 | 0.112E-02 |
| 0.460E+02 | 0.343E+01 | 0.115E-02 |
| 0.470E+02 | 0.353E+01 | 0.118E-02 |
| 0.480E+02 | 0.363E+01 | 0.122E-02 |
| 0.490E+02 | 0.373E+01 | 0.125E-02 |
| 0.500E+02 | 0.383E+01 | 0.128E-02 |
| 0.510E+02 | 0.394E+01 | 0.132E-02 |
| 0.520E+02 | 0.404E+01 | 0.135E-02 |
| 0.530E+02 | 0.415E+01 | 0.139E-02 |
| 0.540E+02 | 0.425E+01 | 0.143E-02 |
| 0.550E+02 | 0.436E+01 | 0.146E-02 |
| 0.560E+02 | 0.447E+01 | 0.150E-02 |
| 0.570E+02 | 0.458E+01 | 0.154E-02 |
| 0.580E+02 | 0.469E+01 | 0.157E-02 |
| 0.590E+02 | 0.481E+01 | 0.161E-02 |

TABLE B-2-2.

Effective Temperature Drop and Thermal Contact Resistance During Start-Up Process (Oil Coolant, P=3500 KPa, Re=1250).

RE = 1250.
PRESSURE (KPa)= 0.
FLUID :OIL

| TIME | D1 | R1 |
|---|---|---|
| 0.120E+03 | 0.899E+01 | 0.375E-02 |
| 0.125E+03 | 0.880E+01 | 0.368E-02 |
| 0.130E+03 | 0.862E+01 | 0.362E-02 |
| 0.135E+03 | 0.844E+01 | 0.356E-02 |
| 0.140E+03 | 0.827E+01 | 0.350E-02 |
| 0.145E+03 | 0.810E+01 | 0.344E-02 |
| 0.150E+03 | 0.793E+01 | 0.338E-02 |
| 0.155E+03 | 0.777E+01 | 0.333E-02 |
| 0.160E+03 | 0.761E+01 | 0.327E-02 |
| 0.165E+03 | 0.745E+01 | 0.322E-02 |
| 0.170E+03 | 0.730E+01 | 0.316E-02 |
| 0.175E+03 | 0.715E+01 | 0.311E-02 |
| 0.180E+03 | 0.700E+01 | 0.306E-02 |
| 0.185E+03 | 0.686E+01 | 0.300E-02 |
| 0.190E+03 | 0.672E+01 | 0.295E-02 |
| 0.195E+03 | 0.658E+01 | 0.290E-02 |
| 0.200E+03 | 0.645E+01 | 0.286E-02 |
| 0.205E+03 | 0.631E+01 | 0.281E-02 |
| 0.210E+03 | 0.618E+01 | 0.276E-02 |
| 0.215E+03 | 0.606E+01 | 0.271E-02 |
| 0.220E+03 | 0.593E+01 | 0.267E-02 |
| 0.225E+03 | 0.581E+01 | 0.262E-02 |
| 0.230E+03 | 0.569E+01 | 0.258E-02 |
| 0.235E+03 | 0.557E+01 | 0.254E-02 |
| 0.240E+03 | 0.546E+01 | 0.249E-02 |
| 0.245E+03 | 0.535E+01 | 0.245E-02 |
| 0.250E+03 | 0.524E+01 | 0.241E-02 |
| 0.255E+03 | 0.513E+01 | 0.237E-02 |
| 0.260E+03 | 0.502E+01 | 0.233E-02 |
| 0.265E+03 | 0.492E+01 | 0.229E-02 |
| 0.270E+03 | 0.482E+01 | 0.225E-02 |
| 0.275E+03 | 0.472E+01 | 0.221E-02 |
| 0.280E+03 | 0.462E+01 | 0.218E-02 |
| 0.285E+03 | 0.453E+01 | 0.214E-02 |
| 0.290E+03 | 0.443E+01 | 0.210E-02 |
| 0.295E+03 | 0.434E+01 | 0.207E-02 |
| 0.300E+03 | 0.425E+01 | 0.203E-02 |
| 0.305E+03 | 0.417E+01 | 0.200E-02 |
| 0.310E+03 | 0.408E+01 | 0.197E-02 |
| 0.315E+03 | 0.400E+01 | 0.193E-02 |
| 0.320E+03 | 0.391E+01 | 0.190E-02 |
| 0.325E+03 | 0.383E+01 | 0.187E-02 |
| 0.330E+03 | 0.375E+01 | 0.184E-02 |
| 0.335E+03 | 0.368E+01 | 0.181E-02 |
| 0.340E+03 | 0.360E+01 | 0.178E-02 |
| 0.345E+03 | 0.353E+01 | 0.175E-02 |
| 0.350E+03 | 0.346E+01 | 0.172E-02 |
| 0.355E+03 | 0.338E+01 | 0.169E-02 |
| 0.360E+03 | 0.331E+01 | 0.166E-02 |
| 0.365E+03 | 0.325E+01 | 0.163E-02 |
| 0.370E+03 | 0.318E+01 | 0.160E-02 |
| 0.375E+03 | 0.311E+01 | 0.158E-02 |
| 0.380E+03 | 0.305E+01 | 0.155E-02 |
| 0.385E+03 | 0.299E+01 | 0.153E-02 |
| 0.390E+03 | 0.293E+01 | 0.150E-02 |
| 0.395E+03 | 0.287E+01 | 0.147E-02 |
| 0.400E+03 | 0.281E+01 | 0.145E-02 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 |

TABLE B-2-3.

Effective Temperature Drop and Thermal Contact Resistance During Shut-Down Process (Oil Coolant, P=0 KPa, Re=1250).

RE = 1250.
PRESSURE (KPa)= 3600.
FLUID :OIL

| TIME | DS | RS |
|---|---|---|
| 0.120E+03 | 0.692E+01 | 0.160E-02 |
| 0.125E+03 | 0.677E+01 | 0.158E-02 |
| 0.130E+03 | 0.663E+01 | 0.155E-02 |
| 0.135E+03 | 0.650E+01 | 0.152E-02 |
| 0.140E+03 | 0.636E+01 | 0.150E-02 |
| 0.145E+03 | 0.623E+01 | 0.147E-02 |
| 0.150E+03 | 0.610E+01 | 0.145E-02 |
| 0.155E+03 | 0.598E+01 | 0.142E-02 |
| 0.160E+03 | 0.586E+01 | 0.140E-02 |
| 0.165E+03 | 0.574E+01 | 0.138E-02 |
| 0.170E+03 | 0.562E+01 | 0.135E-02 |
| 0.175E+03 | 0.550E+01 | 0.133E-02 |
| 0.180E+03 | 0.539E+01 | 0.131E-02 |
| 0.185E+03 | 0.528E+01 | 0.129E-02 |
| 0.190E-03 | 0.517E+01 | 0.126E-02 |
| 0.195E+03 | 0.506E+01 | 0.124E-02 |
| 0.200E+03 | 0.496E+01 | 0.122E-02 |
| 0.205E+03 | 0.486E+01 | 0.120E-02 |
| 0.210E+03 | 0.476E+01 | 0.118E-02 |
| 0.215E+03 | 0.466E+01 | 0.116E-02 |
| 0.220E+03 | 0.456E+01 | 0.114E-02 |
| 0.225E+03 | 0.447E+01 | 0.112E-02 |
| 0.230E+03 | 0.438E+01 | 0.110E-02 |
| 0.235E+03 | 0.429E+01 | 0.109E-02 |
| 0.240E+03 | 0.420E+01 | 0.107E-02 |
| 0.245E+03 | 0.411E+01 | 0.105E-02 |
| 0.250E+03 | 0.403E+01 | 0.103E-02 |
| 0.255E+03 | 0.395E+01 | 0.101E-02 |
| 0.260E+03 | 0.386E+01 | 0.998E-03 |
| 0.265E+03 | 0.379E+01 | 0.981E-03 |
| 0.270E+03 | 0.371E+01 | 0.964E-03 |
| 0.275E+03 | 0.363E+01 | 0.948E-03 |
| 0.280E+03 | 0.356E+01 | 0.932E-03 |
| 0.285E+03 | 0.348E+01 | 0.917E-03 |
| 0.290E+03 | 0.341E+01 | 0.901E-03 |
| 0.295E+03 | 0.334E+01 | 0.886E-03 |
| 0.300E+03 | 0.327E+01 | 0.871E-03 |
| 0.305E+03 | 0.321E+01 | 0.857E-03 |
| 0.310E+03 | 0.314E+01 | 0.842E-03 |
| 0.315E+03 | 0.308E+01 | 0.828E-03 |
| 0.320E+03 | 0.301E+01 | 0.814E-03 |
| 0.325E+03 | 0.295E+01 | 0.800E-03 |
| 0.330E+03 | 0.289E+01 | 0.787E-03 |
| 0.335E+03 | 0.283E+01 | 0.774E-03 |
| 0.340E+03 | 0.277E+01 | 0.761E-03 |
| 0.345E+03 | 0.271E+01 | 0.748E-03 |
| 0.350E+03 | 0.266E+01 | 0.735E-03 |
| 0.355E+03 | 0.260E+01 | 0.723E-03 |
| 0.360E+03 | 0.255E+01 | 0.711E-03 |
| 0.365E+03 | 0.250E+01 | 0.699E-03 |
| 0.370E+03 | 0.245E+01 | 0.687E-03 |
| 0.375E+03 | 0.240E+01 | 0.676E-03 |
| 0.380E+03 | 0.235E+01 | 0.664E-03 |
| 0.385E+03 | 0.230E+01 | 0.653E-03 |
| 0.390E+03 | 0.225E+01 | 0.642E-03 |
| 0.395E+03 | 0.221E+01 | 0.631E-03 |
| 0.400E+03 | 0.216E+01 | 0.621E-03 |
| 0.405E+03 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 0.000E+00 | 0.000E+00 | 0.000E+00 |

TABLE B-2-4.

Effective Temperature Drop and Thermal Contact Resistance During Shut-Down Process (Oil Coolant, P=3500 KPa, Re=1250).

APPENDIX C

## PART 1: EXAMPLES OF TEMPERATURE DISTRIBUTION DURING START-UP PROCESS WITH OIL COOLANT

## TABLE (C-1) - TABLE (C-2)

TABLE C-1. Examples of Temperature Distribution During Start-Up Process with Oil Coolant (P=0 KPa, Re=15).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 72.456
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 91.029 | 89.919 | 88.810 | 87.701 | 86.592 | 85.483 | 84.374 | 83.264 | 82.155 |
| 89.009 | 87.897 | 86.785 | 85.673 | 84.562 | 83.450 | 82.338 | 81.226 | 80.114 |
| 86.839 | 85.726 | 84.614 | 83.501 | 82.388 | 81.276 | 80.163 | 79.050 | 77.937 |
| 84.756 | 83.641 | 82.527 | 81.412 | 80.297 | 79.182 | 78.067 | 76.953 | 75.838 |
| 82.622 | 81.506 | 80.389 | 79.273 | 78.157 | 77.040 | 75.924 | 74.808 | 73.692 |
| 80.588 | 79.468 | 78.349 | 77.230 | 76.111 | 74.991 | 73.872 | 72.753 | 71.634 |
| 78.346 | 77.227 | 76.107 | 74.988 | 73.868 | 72.749 | 71.630 | 70.510 | 69.391 |
| 75.310 | 74.202 | 73.094 | 71.986 | 70.878 | 69.771 | 68.663 | 67.555 | 66.447 |
| 73.040 | 71.933 | 70.826 | 69.718 | 68.611 | 67.504 | 66.397 | 65.289 | 64.182 |
| 70.741 | 69.635 | 68.529 | 67.423 | 66.317 | 65.210 | 64.104 | 62.998 | 61.892 |
| 67.414 | 66.326 | 65.238 | 64.149 | 63.061 | 61.972 | 60.884 | 59.795 | 58.707 |
| 62.700 | 61.654 | 60.608 | 59.561 | 58.515 | 57.469 | 56.422 | 55.376 | 54.330 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 81.694
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 102.898 | 101.644 | 100.390 | 99.137 | 97.883 | 96.629 | 95.375 | 94.121 | 92.868 |
| 100.838 | 99.578 | 98.319 | 97.059 | 95.799 | 94.540 | 93.280 | 92.021 | 90.761 |
| 98.457 | 97.195 | 95.933 | 94.672 | 93.410 | 92.149 | 90.887 | 89.626 | 88.364 |
| 96.265 | 94.998 | 93.732 | 92.466 | 91.200 | 89.934 | 88.668 | 87.402 | 86.135 |
| 93.956 | 92.687 | 91.417 | 90.148 | 88.878 | 87.609 | 86.340 | 85.070 | 83.801 |
| 91.877 | 90.601 | 89.325 | 88.049 | 86.773 | 85.497 | 84.221 | 82.945 | 81.669 |
| 89.370 | 88.093 | 86.816 | 85.539 | 84.263 | 82.986 | 81.709 | 80.432 | 79.155 |
| 85.023 | 83.773 | 82.522 | 81.271 | 80.020 | 78.770 | 77.519 | 76.268 | 75.017 |

TABLE C-1. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 82.417 | 81.167 | 79.918 | 78.668 | 77.419 | 76.170 | 74.920 | 73.671 | 72.422 |
| 79.744 | 78.497 | 77.250 | 76.003 | 74.756 | 73.509 | 72.262 | 71.015 | 69.768 |
| 74.767 | 73.560 | 72.353 | 71.146 | 69.939 | 68.732 | 67.525 | 66.317 | 65.110 |
| 66.855 | 65.739 | 64.623 | 63.508 | 62.392 | 61.276 | 60.161 | 59.045 | 57.929 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 30.00
ENDING TIME = 40.00
AVERAGE TEMPERATURE = 92.659
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 116.999 | 115.574 | 114.148 | 112.722 | 111.297 | 109.871 | 108.445 | 107.020 | 105.594 |
| 114.890 | 113.454 | 112.019 | 110.584 | 109.149 | 107.714 | 106.279 | 104.844 | 103.409 |
| 112.263 | 110.824 | 109.386 | 107.947 | 106.509 | 105.070 | 103.632 | 102.193 | 100.755 |
| 109.947 | 108.501 | 107.055 | 105.609 | 104.163 | 102.717 | 101.271 | 99.824 | 98.378 |
| 107.432 | 105.980 | 104.529 | 103.077 | 101.626 | 100.175 | 98.723 | 97.272 | 95.820 |
| 105.313 | 103.850 | 102.388 | 100.925 | 99.462 | 98.000 | 96.537 | 95.074 | 93.612 |
| 102.537 | 101.072 | 99.607 | 98.142 | 95.677 | 95.212 | 93.747 | 92.282 | 90.817 |
| 96.546 | 95.126 | 93.706 | 92.285 | 90.865 | 89.445 | 98.025 | 86.604 | 85.184 |
| 93.536 | 92.118 | 90.700 | 89.282 | 87.864 | 86.446 | 85.028 | 83.610 | 82.192 |
| 90.413 | 89.000 | 87.586 | 86.172 | 84.758 | 83.344 | 81.931 | 80.517 | 79.103 |
| 83.396 | 82.050 | 80.703 | 79.357 | 78.011 | 76.664 | 75.318 | 73.971 | 72.625 |
| 71.698 | 70.501 | 69.305 | 68.108 | 66.912 | 65.715 | 64.519 | 63.322 | 62.126 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 40.00
ENDING TIME = 50.00
AVERAGE TEMPERATURE =105.720
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 133.815 | 132.185 | 130.554 | 128.924 | 127.293 | 125.663 | 124.032 | 122.402 | 120.771 |
| 131.645 | 130.001 | 128.356 | 126.712 | 125.067 | 123.423 | 121.779 | 120.134 | 118.490 |
| 128.732 | 127.083 | 125.433 | 123.784 | 122.134 | 120.485 | 118.835 | 117.186 | 115.536 |
| 126.277 | 124.616 | 122.955 | 121.294 | 119.634 | 117.973 | 116.312 | 114.651 | 112.990 |

TABLE C-1. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 123.515 | 121.847 | 120.178 | 118.509 | 116.840 | 115.172 | 113.503 | 111.834 | 110.165 |
| 121.365 | 119.679 | 117.994 | 116.308 | 114.623 | 112.937 | 111.252 | 109.566 | 107.881 |
| 118.325 | 116.635 | 114.944 | 113.253 | 111.563 | 109.872 | 108.182 | 106.491 | 104.800 |
| 110.267 | 108.645 | 107.023 | 105.400 | 103.778 | 102.156 | 100.534 | 98.912 | 97.290 |
| 106.771 | 105.153 | 103.534 | 101.915 | 100.297 | 98.678 | 97.059 | 95.441 | 93.822 |
| 103.105 | 101.493 | 99.880 | 98.268 | 96.656 | 95.044 | 93.431 | 91.819 | 90.207 |
| 93.553 | 92.043 | 90.532 | 89.022 | 87.511 | 86.001 | 84.490 | 82.980 | 81.469 |
| 77.337 | 76.047 | 74.756 | 73.466 | 72.175 | 70.884 | 69.594 | 68.303 | 67.013 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 50.00
ENDING TIME = 60.00
AVERAGE TEMPERATURE =121.337
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OTL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 153.949 | 152.073 | 150.197 | 148.321 | 146.446 | 144.570 | 142.594 | 140.818 | 138.942 |
| 151.703 | 149.809 | 147.913 | 146.019 | 144.124 | 142.229 | 140.334 | 138.439 | 136.544 |
| 148.457 | 146.555 | 144.652 | 142.750 | 140.848 | 138.946 | 137.043 | 135.141 | 133.239 |
| 145.844 | 143.925 | 142.007 | 140.089 | 138.171 | 136.252 | 134.334 | 132.416 | 130.498 |
| 142.787 | 140.858 | 138.929 | 137.000 | 135.070 | 133.141 | 131.212 | 129.283 | 127.354 |
| 140.619 | 138.656 | 136.713 | 134.760 | 132.807 | 130.854 | 128.901 | 126.948 | 124.995 |
| 137.337 | 135.374 | 133.412 | 131.450 | 129.488 | 127.525 | 125.563 | 123.601 | 121.639 |
| 126.667 | 124.804 | 122.941 | 121.077 | 119.214 | 117.350 | 115.487 | 113.624 | 111.760 |
| 122.586 | 120.728 | 118.869 | 117.011 | 115.152 | 113.294 | 111.436 | 109.577 | 107.719 |
| 118.260 | 116.411 | 114.561 | 112.712 | 110.863 | 109.014 | 107.164 | 105.315 | 103.466 |
| 105.547 | 103.842 | 102.138 | 100.434 | 98.730 | 97.026 | 95.322 | 93.618 | 91.914 |
| 83.904 | 82.504 | 81.104 | 79.704 | 78.304 | 76.904 | 75.503 | 74.103 | 72.703 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 60.00
ENDING TIME = 70.00
AVERAGE TEMPERATURE =140.085
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

TABLE C-1. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 178.154 | 175.983 | 173.812 | 171.641 | 169.470 | 167.300 | 165.129 | 162.958 | 160.767 |
| 175.814 | 173.618 | 171.422 | 169.225 | 167.029 | 164.833 | 162.637 | 160.441 | 158.245 |
| 172.177 | 169.971 | 167.765 | 165.559 | 163.352 | 161.146 | 158.940 | 156.734 | 154.528 |
| 169.384 | 167.156 | 164.928 | 162.701 | 160.473 | 158.245 | 156.017 | 153.789 | 151.561 |
| 165.972 | 163.730 | 161.487 | 159.245 | 157.002 | 154.760 | 152.518 | 150.275 | 148.033 |
| 163.806 | 161.531 | 159.256 | 156.981 | 154.706 | 152.431 | 150.156 | 147.881 | 145.606 |
| 160.327 | 158.036 | 155.745 | 153.455 | 151.164 | 148.873 | 146.583 | 144.292 | 142.001 |
| 146.351 | 144.198 | 142.045 | 139.892 | 137.739 | 135.586 | 133.433 | 131.280 | 129.127 |
| 141.559 | 139.413 | 137.267 | 135.121 | 132.975 | 130.829 | 128.683 | 126.537 | 124.391 |
| 136.429 | 134.295 | 132.162 | 130.029 | 127.895 | 125.762 | 123.629 | 121.495 | 119.362 |
| 119.758 | 117.825 | 115.891 | 113.958 | 112.024 | 110.091 | 108.157 | 106.224 | 104.290 |
| 91.557 | 90.029 | 88.501 | 86.973 | 85.445 | 83.917 | 82.390 | 80.862 | 79.334 |

TABLE C-2. Examples of Temperature Distribution During Start-Up Process with Oil Coolant (P=3500, Re=15).

```
ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 10.00
ENDING TIME = 20.00
AVERAGE TEMPERATURE = 74.505
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:oil
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 91.029 | 90.107 | 89.186 | 88.264 | 87.343 | 86.421 | 85.500 | 84.578 | 83.657 |
| 89.197 | 88.273 | 87.350 | 86.426 | 85.502 | 84.578 | 83.655 | 82.731 | 81.807 |
| 87.216 | 86.291 | 85.367 | 84.442 | 83.518 | 82.594 | 81.669 | 80.745 | 79.820 |
| 85.322 | 84.396 | 83.470 | 82.544 | 81.617 | 80.691 | 79.765 | 78.839 | 77.913 |
| 83.377 | 82.450 | 81.522 | 80.595 | 79.668 | 78.740 | 77.813 | 76.886 | 75.958 |
| 81.534 | 80.605 | 79.675 | 78.745 | 77.815 | 76.885 | 75.955 | 75.025 | 74.096 |
| 79.482 | 78.552 | 77.622 | 76.692 | 75.762 | 74.832 | 73.902 | 72.972 | 72.043 |
| 76.622 | 75.702 | 74.781 | 73.861 | 72.940 | 72.020 | 71.100 | 70.179 | 69.259 |
| 74.539 | 73.619 | 72.699 | 71.779 | 70.859 | 69.939 | 69.020 | 68.100 | 67.180 |
| 72.426 | 71.507 | 70.588 | 69.669 | 68.750 | 67.831 | 66.912 | 65.993 | 65.074 |
| 69.256 | 68.352 | 67.447 | 66.543 | 65.639 | 64.735 | 63.830 | 62.926 | 62.022 |
| 64.648 | 63.778 | 62.909 | 62.040 | 61.171 | 60.301 | 59.432 | 58.563 | 57.693 |

```
ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 20.00
ENDING TIME = 30.00
AVERAGE TEMPERATURE = 83.995
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:oil
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 102.898 | 101.856 | 100.815 | 99.773 | 98.731 | 97.690 | 96.648 | 95.606 | 94.565 |
| 101.051 | 100.004 | 98.958 | 97.912 | 96.865 | 95.819 | 94.772 | 93.726 | 92.679 |
| 98.883 | 97.835 | 96.787 | 95.739 | 94.691 | 93.643 | 92.595 | 91.547 | 90.499 |
| 96.907 | 95.855 | 94.803 | 93.752 | 92.700 | 91.648 | 90.596 | 89.544 | 88.492 |
| 94.815 | 93.760 | 92.706 | 91.651 | 90.597 | 89.542 | 88.487 | 87.433 | 86.378 |
| 92.956 | 91.896 | 90.836 | 89.776 | 88.716 | 87.656 | 86.596 | 85.536 | 84.475 |
| 90.666 | 89.606 | 88.545 | 87.484 | 86.423 | 85.362 | 84.301 | 83.241 | 82.180 |
| 86.505 | 85.466 | 84.427 | 83.387 | 82.348 | 81.309 | 80.270 | 79.231 | 78.192 |

TABLE C-2. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 84.106 | 83.070 | 82.032 | 80.994 | 79.956 | 78.918 | 77.880 | 76.842 | 75.804 |
| 81.643 | 80.607 | 79.571 | 78.535 | 77.499 | 76.463 | 75.427 | 74.391 | 73.355 |
| 76.810 | 75.807 | 74.804 | 73.801 | 72.798 | 71.795 | 70.793 | 69.790 | 68.787 |
| 68.931 | 68.004 | 67.077 | 66.151 | 65.224 | 64.297 | 63.370 | 62.443 | 61.516 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 30.00
ENDING TIME = 40.00
AVERAGE TEMPERATURE = 95.257
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:oil

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 116.999 | 115.815 | 114.630 | 113.446 | 112.262 | 111.077 | 109.893 | 108.708 | 107.524 |
| 115.132 | 113.940 | 112.748 | 111.556 | 110.363 | 109.171 | 107.979 | 106.786 | 105.594 |
| 112.749 | 111.554 | 110.353 | 109.164 | 107.969 | 106.774 | 105.579 | 104.384 | 103.189 |
| 110.681 | 109.480 | 108.279 | 107.077 | 105.876 | 104.674 | 103.473 | 102.271 | 101.070 |
| 108.414 | 107.208 | 106.002 | 104.797 | 103.591 | 102.385 | 101.179 | 99.973 | 98.767 |
| 106.550 | 105.335 | 104.120 | 102.905 | 101.690 | 100.474 | 99.259 | 98.044 | 96.829 |
| 104.024 | 102.807 | 101.590 | 100.373 | 99.155 | 97.938 | 96.721 | 95.504 | 94.287 |
| 98.229 | 97.049 | 95.869 | 94.689 | 93.509 | 92.329 | 91.149 | 89.969 | 88.789 |
| 95.456 | 94.277 | 93.099 | 91.921 | 90.743 | 89.565 | 88.387 | 87.209 | 86.031 |
| 92.566 | 91.392 | 90.217 | 89.043 | 87.868 | 86.693 | 85.519 | 84.344 | 83.170 |
| 85.675 | 84.556 | 83.437 | 82.319 | 81.200 | 80.081 | 78.963 | 77.844 | 76.725 |
| 73.925 | 72.931 | 71.937 | 70.943 | 69.948 | 68.954 | 67.960 | 66.966 | 65.972 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 40.00
ENDING TIME = 50.00
AVERAGE TEMPERATURE =108.672
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:oil

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 133.815 | 132.461 | 131.106 | 129.752 | 128.397 | 127.042 | 125.688 | 124.333 | 122.978 |
| 131.923 | 130.557 | 129.191 | 127.825 | 126.459 | 125.092 | 123.726 | 122.360 | 120.994 |
| 129.290 | 127.920 | 126.550 | 125.179 | 123.809 | 122.438 | 121.068 | 119.697 | 118.327 |
| 127.120 | 125.740 | 124.360 | 122.981 | 121.601 | 120.221 | 118.841 | 117.461 | 116.081 |

TABLE C-2. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 124.645 | 123.258 | 121.872 | 120.486 | 119.099 | 117.713 | 116.326 | 114.940 | 113.554 |
| 122.791 | 121.391 | 119.990 | 118.590 | 117.189 | 115.789 | 114.389 | 112.988 | 111.585 |
| 120.042 | 118.637 | 117.232 | 115.828 | 114.423 | 113.019 | 111.614 | 110.210 | 108.809 |
| 112.188 | 110.840 | 109.493 | 108.145 | 106.797 | 105.450 | 104.102 | 102.754 | 101.407 |
| 108.962 | 107.617 | 106.273 | 104.928 | 103.583 | 102.238 | 100.894 | 99.549 | 98.204 |
| 105.560 | 104.221 | 102.881 | 101.542 | 100.202 | 98.863 | 97.523 | 96.184 | 94.844 |
| 96.109 | 94.854 | 93.599 | 92.344 | 91.089 | 89.834 | 88.579 | 87.325 | 86.070 |
| 79.739 | 78.667 | 77.595 | 76.523 | 75.451 | 74.378 | 73.306 | 72.234 | 71.162 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 50.00
ENDING TIME = 60.00
AVERAGE TEMPERATURE =124.712
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:oil

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 153.949 | 152.391 | 150.832 | 149.274 | 147.715 | 146.157 | 144.598 | 143.040 | 141.481 |
| 152.024 | 150.450 | 148.875 | 147.301 | 145.727 | 144.152 | 142.578 | 141.004 | 139.429 |
| 149.101 | 147.520 | 145.940 | 144.359 | 142.779 | 141.199 | 139.618 | 138.038 | 136.458 |
| 146.817 | 145.224 | 143.630 | 142.036 | 140.443 | 138.849 | 137.255 | 135.662 | 134.068 |
| 144.093 | 142.490 | 140.887 | 139.284 | 137.682 | 136.079 | 134.476 | 132.874 | 131.271 |
| 142.271 | 140.648 | 139.026 | 137.403 | 135.781 | 134.158 | 132.536 | 130.913 | 129.291 |
| 139.329 | 137.698 | 136.068 | 134.438 | 132.808 | 131.178 | 129.547 | 127.917 | 126.287 |
| 128.874 | 127.326 | 125.778 | 124.230 | 122.682 | 121.134 | 119.586 | 118.038 | 116.489 |
| 125.101 | 123.557 | 122.013 | 120.470 | 118.926 | 117.382 | 115.838 | 114.294 | 112.750 |
| 121.076 | 119.539 | 118.003 | 116.467 | 114.930 | 113.394 | 111.858 | 110.321 | 108.785 |
| 108.430 | 107.014 | 105.598 | 104.183 | 102.767 | 101.351 | 99.935 | 98.520 | 97.104 |
| 86.510 | 85.347 | 84.184 | 83.021 | 81.857 | 80.694 | 79.531 | 78.368 | 77.204 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME = 60.00
ENDING TIME = 70.00
AVERAGE TEMPERATURE =143.966
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:oil

TABLE C-2. Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 178.154 | 176.350 | 174.547 | 172.743 | 170.940 | 169.136 | 167.333 | 165.529 | 163.725 |
| 176.185 | 174.361 | 172.536 | 170.712 | 168.887 | 167.063 | 165.238 | 163.414 | 161.589 |
| 172.924 | 171.091 | 169.258 | 167.425 | 165.592 | 163.759 | 161.926 | 160.093 | 158.2[illegible] |
| 170.515 | 168.664 | 166.813 | 164.962 | 163.111 | 161.260 | 159.410 | 157.559 | 155.708 |
| 167.490 | 165.627 | 163.764 | 161.901 | 160.038 | 158.175 | 156.312 | 154.449 | 152.586 |
| 165.731 | 163.841 | 161.951 | 160.061 | 158.171 | 156.280 | 154.390 | 152.500 | 150.610 |
| 162.652 | 160.749 | 158.846 | 156.943 | 155.040 | 153.137 | 151.234 | 149.331 | 147.427 |
| 148.901 | 147.112 | 145.323 | 143.535 | 141.746 | 139.957 | 138.169 | 136.380 | 134.591 |
| 144.464 | 142.681 | 140.898 | 139.115 | 137.332 | 135.549 | 133.766 | 131.983 | 130.201 |
| 139.677 | 137.905 | 136.133 | 134.360 | 132.588 | 130.815 | 129.043 | 127.271 | 125.498 |
| 123.030 | 121.423 | 119.817 | 118.211 | 116.604 | 114.998 | 113.392 | 111.785 | 110.179 |
| 94.401 | 93.131 | 91.862 | 90.592 | 89.323 | 88.054 | 86.784 | 85.515 | 84.246 |

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## PART 2: EXAMPLES OF TEMPERATURE DISTRIBUTION DURING SHUT-DOWN PROCESS WITH OIL COOLANT

### TABLE (C-4) - TABLE (C-5)

TABLE C-5. Example of Temperature Distribution During Shut-Down Process with Oil Coolant (P=0 KPa, Re=15).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME -120.00
ENDING TIME -150.00
AVERAGE TEMPERATURE -185.641
PRESURE- 0.0 KPa
REYNOLD'S NUMBER- 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 208.054 | 206.636 | 205.219 | 203.802 | 202.384 | 200.967 | 199.550 | 198.133 | 196.715 |
| 205.684 | 204.267 | 202.850 | 201.432 | 200.015 | 198.598 | 197.181 | 195.764 | 194.346 |
| 202.446 | 201.034 | 199.623 | 198.212 | 196.801 | 195.390 | 193.979 | 192.568 | 191.157 |
| 199.656 | 198.242 | 196.834 | 195.426 | 194.018 | 192.610 | 191.202 | 189.794 | 168.356 |
| 197.062 | 195.656 | 194.250 | 192.843 | 191.437 | 190.031 | 188.625 | 187.218 | 165.812 |
| 194.478 | 193.073 | 191.669 | 190.264 | 188.860 | 187.455 | 186.051 | 184.646 | 183.242 |
| 191.902 | 190.499 | 189.096 | 187.694 | 186.291 | 184.888 | 183.485 | 182.082 | 180.680 |
| 189.291 | 187.890 | 186.490 | 185.089 | 183.688 | 182.287 | 180.887 | 179.466 | 176.085 |
| 186.737 | 185.338 | 183.939 | 162.539 | 181.140 | 179.741 | 178.342 | 176.943 | 175.544 |
| 184.182 | 182.784 | 181.387 | 179.989 | 178.592 | 177.194 | 175.797 | 174.400 | 173.002 |
| 181.741 | 180.345 | 178.948 | 177.551 | 176.155 | 174.758 | 173.362 | 171.965 | 170.569 |
| 179.177 | 177.782 | 176.387 | 174.993 | 173.598 | 172.203 | 170.809 | 169.414 | 168.019 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME -150.00
ENDING TIME -180.00
AVERAGE TEMPERATURE -171.446
PRESURE- 0.0 KPa
REYNOLD'S NUMBER- 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 194.247 | 192.924 | 191.600 | 190.277 | 188.954 | 187.631 | 186.308 | 184.964 | 183.661 |
| 192.026 | 190.703 | 189.380 | 188.057 | 186.734 | 185.410 | 184.087 | 182.764 | 181.441 |
| 187.942 | 186.632 | 185.322 | 184.012 | 182.702 | 181.392 | 180.082 | 178.772 | 177.462 |
| 184.875 | 183.571 | 182.268 | 180.964 | 179.660 | 178.356 | 177.052 | 175.749 | 174.445 |
| 182.200 | 180.899 | 179.599 | 178.299 | 176.999 | 175.699 | 174.398 | 173.098 | 171.798 |
| 179.533 | 178.236 | 176.940 | 175.643 | 174.346 | 173.050 | 171.753 | 170.457 | 169.160 |
| 176.884 | 175.591 | 174.298 | 173.005 | 171.712 | 170.419 | 169.126 | 167.833 | 166.540 |
| 174.164 | 172.875 | 171.586 | 170.297 | 169.008 | 167.720 | 166.431 | 165.142 | 163.853 |

TABLE C-3. (Continued)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 171.561 | 170.276 | 168.990 | 167.705 | 166.419 | 165.134 | 163.849 | 162.563 | 161.276 |
| 168.957 | 167.675 | 166.393 | 165.112 | 163.830 | 162.548 | 161.266 | 159.984 | 158.702 |
| 166.591 | 165.311 | 164.031 | 162.751 | 161.471 | 160.190 | 158.919 | 157.630 | 156.350 |
| 163.970 | 162.694 | 161.417 | 160.141 | 158.864 | 157.588 | 156.312 | 155.035 | 153.759 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =180.00
ENDING TIME =210.00
AVERAGE TEMPERATURE =156.126
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 179.207 | 177.986 | 176.765 | 175.544 | 174.324 | 173.103 | 171.882 | 170.661 | 169.441 |
| 177.148 | 175.927 | 174.707 | 173.486 | 172.266 | 171.045 | 169.825 | 168.604 | 167.383 |
| 172.182 | 170.982 | 169.782 | 168.582 | 167.382 | 166.182 | 164.982 | 163.781 | 162.581 |
| 168.886 | 167.695 | 166.504 | 165.313 | 164.122 | 162.931 | 161.740 | 160.549 | 159.358 |
| 166.137 | 164.951 | 163.766 | 162.580 | 161.395 | 160.209 | 159.024 | 157.838 | 156.652 |
| 163.402 | 162.222 | 161.042 | 159.862 | 158.682 | 157.501 | 156.321 | 155.141 | 153.961 |
| 160.696 | 159.521 | 158.346 | 157.172 | 155.997 | 154.822 | 153.646 | 152.473 | 151.298 |
| 157.883 | 156.715 | 155.546 | 154.378 | 153.210 | 152.041 | 150.873 | 149.705 | 148.536 |
| 155.250 | 154.086 | 152.923 | 151.760 | 150.597 | 149.434 | 148.270 | 147.107 | 145.944 |
| 152.616 | 151.458 | 150.300 | 149.142 | 147.984 | 146.826 | 145.668 | 144.510 | 143.352 |
| 150.340 | 149.185 | 148.030 | 146.875 | 145.719 | 144.564 | 143.409 | 142.253 | 141.098 |
| 147.682 | 146.533 | 145.383 | 144.233 | 143.084 | 141.934 | 140.785 | 139.635 | 138.486 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =210.00
ENDING TIME =240.00
AVERAGE TEMPERATURE =140.193
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 163.371 | 162.258 | 161.145 | 160.032 | 158.919 | 157.807 | 156.694 | 155.581 | 154.468 |
| 161.484 | 160.371 | 159.259 | 158.146 | 157.034 | 155.921 | 154.808 | 153.696 | 152.583 |
| 155.669 | 154.584 | 153.499 | 152.414 | 151.329 | 150.244 | 149.159 | 148.074 | 146.989 |
| 152.201 | 151.128 | 150.054 | 148.981 | 147.908 | 146.834 | 145.761 | 144.688 | 143.614 |

TABLE C-3. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 149.403 | 148.337 | 147.271 | 146.204 | 145.138 | 144.072 | 143.006 | 141.940 | 140.874 |
| 146.626 | 145.567 | 144.508 | 143.449 | 142.390 | 141.331 | 140.272 | 139.213 | 138.154 |
| 143.889 | 142.837 | 141.785 | 140.734 | 139.682 | 138.630 | 137.578 | 136.526 | 135.474 |
| 141.015 | 139.971 | 138.926 | 137.884 | 136.841 | 135.797 | 134.754 | 133.710 | 132.667 |
| 138.378 | 137.341 | 136.304 | 135.267 | 134.230 | 133.194 | 132.157 | 131.120 | 130.083 |
| 135.742 | 134.712 | 133.682 | 132.652 | 131.622 | 130.592 | 129.562 | 128.532 | 127.502 |
| 133.575 | 132.548 | 131.522 | 130.495 | 129.469 | 128.443 | 127.416 | 126.390 | 125.363 |
| 130.910 | 129.891 | 128.872 | 127.853 | 126.834 | 125.815 | 124.796 | 123.777 | 122.758 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =124.137
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 147.169 | 146.167 | 145.164 | 144.162 | 143.159 | 142.157 | 141.154 | 140.152 | 139.149 |
| 145.459 | 144.457 | 143.455 | 142.452 | 141.450 | 140.448 | 139.446 | 138.443 | 137.441 |
| 138.889 | 137.921 | 136.953 | 135.985 | 135.017 | 134.048 | 133.080 | 132.112 | 131.144 |
| 135.315 | 134.361 | 133.407 | 132.453 | 131.498 | 130.544 | 129.590 | 128.536 | 127.682 |
| 132.503 | 131.557 | 130.612 | 129.666 | 128.721 | 127.775 | 126.830 | 125.884 | 124.939 |
| 129.719 | 128.782 | 127.845 | 126.909 | 125.972 | 125.035 | 124.098 | 123.161 | 122.224 |
| 126.987 | 126.056 | 125.130 | 124.202 | 123.274 | 122.345 | 121.417 | 120.489 | 119.560 |
| 124.092 | 123.174 | 122.255 | 121.337 | 120.419 | 119.501 | 118.582 | 117.664 | 116.746 |
| 121.485 | 120.575 | 119.665 | 118.755 | 117.844 | 116.934 | 116.024 | 115.114 | 114.203 |
| 118.883 | 117.981 | 117.079 | 116.177 | 115.275 | 114.373 | 113.471 | 112.569 | 111.667 |
| 116.842 | 115.944 | 115.046 | 114.148 | 113.250 | 112.353 | 111.455 | 110.557 | 109.659 |
| 114.209 | 113.320 | 112.431 | 111.542 | 110.653 | 109.764 | 108.875 | 107.986 | 107.097 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE =108.397
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

TABLE C-3. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 131.003 | 130.110 | 129.218 | 128.325 | 127.433 | 126.541 | 125.648 | 124.756 | 123.863 |
| 129.470 | 128.578 | 127.686 | 126.794 | 125.901 | 125.009 | 124.117 | 123.225 | 122.333 |
| 122.287 | 121.435 | 120.583 | 119.730 | 118.878 | 118.025 | 117.173 | 116.321 | 115.468 |
| 118.682 | 117.845 | 117.008 | 116.171 | 115.334 | 114.497 | 113.660 | 112.823 | 111.986 |
| 115.896 | 115.069 | 114.242 | 113.414 | 112.587 | 111.760 | 110.933 | 110.106 | 109.279 |
| 113.145 | 112.328 | 111.511 | 110.694 | 109.877 | 109.060 | 108.243 | 107.426 | 106.608 |
| 110.457 | 109.650 | 108.843 | 108.035 | 107.228 | 106.420 | 105.613 | 104.805 | 103.998 |
| 107.591 | 106.794 | 105.998 | 105.202 | 104.406 | 103.610 | 102.813 | 102.017 | 101.221 |
| 105.052 | 104.265 | 103.478 | 102.691 | 101.904 | 101.117 | 100.329 | 99.542 | 98.755 |
| 102.522 | 101.744 | 100.966 | 100.188 | 99.410 | 98.632 | 97.854 | 97.077 | 96.299 |
| 100.623 | 99.850 | 99.076 | 98.303 | 97.530 | 96.757 | 95.984 | 95.210 | 94.437 |
| 98.064 | 97.301 | 96.537 | 95.774 | 95.011 | 94.247 | 93.484 | 92.721 | 91.957 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =300.00
ENDING TIME =330.00
AVERAGE TEMPERATURE = 93.345
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 115.230 | 114.445 | 113.660 | 112.875 | 112.090 | 111.305 | 110.520 | 109.735 | 108.950 |
| 113.871 | 113.086 | 112.302 | 111.517 | 110.733 | 109.948 | 109.163 | 108.379 | 107.594 |
| 106.254 | 105.513 | 104.773 | 104.032 | 103.291 | 102.551 | 101.810 | 101.069 | 100.329 |
| 102.690 | 101.966 | 101.242 | 100.518 | 99.793 | 99.069 | 98.345 | 97.621 | 96.897 |
| 99.973 | 99.259 | 98.546 | 97.833 | 97.119 | 96.406 | 95.692 | 94.979 | 94.266 |
| 97.299 | 96.597 | 95.894 | 95.191 | 94.489 | 93.786 | 93.083 | 92.381 | 91.678 |
| 94.698 | 94.005 | 93.313 | 92.621 | 91.929 | 91.237 | 90.544 | 89.852 | 89.160 |
| 91.908 | 91.228 | 90.548 | 89.868 | 89.188 | 88.508 | 87.828 | 87.147 | 86.467 |
| 89.476 | 88.806 | 88.136 | 87.465 | 86.795 | 86.124 | 85.454 | 84.784 | 84.113 |
| 87.057 | 86.396 | 85.736 | 85.075 | 84.415 | 83.754 | 83.094 | 82.433 | 81.773 |
| 85.314 | 84.658 | 84.003 | 83.347 | 82.692 | 82.036 | 81.381 | 80.725 | 80.069 |
| 82.871 | 82.225 | 81.580 | 80.935 | 80.290 | 79.645 | 79.000 | 78.355 | 77.710 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =330.00

TABLE C-3. (Continued).

ENDING TIME =360.00
AVERAGE TEMPERATURE = 79.277
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 100.154 | 99.472 | 98.790 | 98.107 | 97.425 | 96.743 | 96.061 | 95.378 | 94.696 |
| 98.964 | 98.282 | 97.600 | 96.918 | 96.236 | 95.554 | 94.872 | 94.190 | 93.509 |
| 91.108 | 90.473 | 89.838 | 89.203 | 88.568 | 87.933 | 87.298 | 86.663 | 86.028 |
| 87.656 | 87.038 | 86.419 | 85.801 | 85.183 | 84.565 | 83.947 | 83.329 | 82.710 |
| 85.050 | 84.443 | 83.836 | 83.229 | 82.622 | 82.015 | 81.408 | 80.801 | 80.194 |
| 82.494 | 81.898 | 81.303 | 80.707 | 80.111 | 79.515 | 78.920 | 78.324 | 77.728 |
| 80.019 | 79.434 | 78.849 | 78.264 | 77.679 | 77.094 | 76.509 | 75.924 | 75.339 |
| 77.355 | 76.782 | 76.210 | 75.637 | 75.065 | 74.493 | 73.920 | 73.348 | 72.775 |
| 75.065 | 74.502 | 73.940 | 73.377 | 72.815 | 72.253 | 71.690 | 71.128 | 70.565 |
| 72.792 | 72.240 | 71.687 | 71.135 | 70.583 | 70.030 | 69.478 | 68.926 | 68.374 |
| 71.215 | 70.667 | 70.120 | 69.573 | 69.026 | 68.478 | 67.931 | 67.384 | 66.837 |
| 68.924 | 68.388 | 67.851 | 67.315 | 66.778 | 66.242 | 65.705 | 65.169 | 64.632 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =360.00
ENDING TIME =390.00
AVERAGE TEMPERATURE = 66.407
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 86.019 | 85.433 | 84.847 | 84.261 | 83.675 | 83.089 | 82.503 | 81.917 | 81.331 |
| 84.987 | 84.402 | 83.816 | 83.231 | 82.645 | 82.060 | 81.474 | 80.888 | 80.303 |
| 77.094 | 76.556 | 76.019 | 75.482 | 74.944 | 74.407 | 73.870 | 73.332 | 72.795 |
| 73.814 | 73.293 | 72.773 | 72.252 | 71.732 | 71.211 | 70.691 | 70.170 | 69.650 |
| 71.357 | 70.848 | 70.338 | 69.829 | 69.320 | 68.811 | 68.302 | 67.792 | 67.283 |
| 68.957 | 68.459 | 67.961 | 67.463 | 66.965 | 66.467 | 65.969 | 65.471 | 64.973 |
| 66.642 | 66.155 | 65.668 | 65.181 | 64.694 | 64.206 | 63.719 | 63.232 | 62.745 |
| 64.146 | 63.671 | 63.197 | 62.722 | 62.247 | 61.772 | 61.298 | 60.823 | 60.348 |
| 62.028 | 61.563 | 61.098 | 60.634 | 60.169 | 59.704 | 59.239 | 58.775 | 58.310 |
| 59.931 | 59.477 | 59.022 | 58.567 | 58.112 | 57.658 | 57.203 | 56.748 | 56.294 |

TABLE C-3. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 58.525 | 58.075 | 57.626 | 57.176 | 56.726 | 56.277 | 55.827 | 55.377 | 54.927 |
| 56.419 | 55.980 | 55.541 | 55.102 | 54.662 | 54.223 | 53.784 | 53.345 | 52.906 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 54.867
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 73.003 | 72.506 | 72.009 | 71.511 | 71.014 | 70.517 | 70.019 | 69.522 | 69.025 |
| 72.119 | 71.622 | 71.125 | 70.628 | 70.132 | 69.635 | 69.136 | 68.641 | 68.144 |
| 64.377 | 63.928 | 63.480 | 63.031 | 62.582 | 62.133 | 61.685 | 61.236 | 60.787 |
| 61.320 | 60.888 | 60.455 | 60.023 | 59.590 | 59.158 | 58.726 | 58.293 | 57.861 |
| 59.044 | 58.622 | 58.201 | 57.780 | 57.358 | 56.937 | 56.516 | 56.094 | 55.673 |
| 56.829 | 56.419 | 56.008 | 55.598 | 55.187 | 54.777 | 54.367 | 53.956 | 53.546 |
| 54.703 | 54.304 | 53.904 | 53.504 | 53.104 | 52.704 | 52.304 | 51.904 | 51.504 |
| 52.409 | 52.021 | 51.633 | 51.245 | 50.857 | 50.469 | 50.082 | 49.694 | 49.306 |
| 50.485 | 50.106 | 49.728 | 49.350 | 48.972 | 48.593 | 48.215 | 47.837 | 47.459 |
| 48.587 | 48.218 | 47.649 | 47.481 | 47.112 | 46.743 | 46.375 | 46.006 | 45.638 |
| 47.352 | 46.989 | 46.625 | 46.261 | 45.897 | 45.533 | 45.169 | 44.805 | 44.441 |
| 45.453 | 45.099 | 44.745 | 44.391 | 44.038 | 43.684 | 43.330 | 42.976 | 42.622 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =420.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 44.717
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 61.222 | 60.805 | 60.388 | 59.971 | 59.554 | 59.137 | 58.720 | 58.303 | 57.886 |
| 60.473 | 60.057 | 59.640 | 59.223 | 58.807 | 58.390 | 57.973 | 57.557 | 57.140 |
| 53.051 | 52.681 | 52.311 | 51.942 | 51.572 | 51.202 | 50.832 | 50.462 | 50.093 |
| 50.255 | 49.900 | 49.546 | 49.191 | 48.837 | 48.483 | 48.128 | 47.774 | 47.419 |
| 48.182 | 47.838 | 47.494 | 47.151 | 46.807 | 46.463 | 46.119 | 45.775 | 45.431 |
| 46.175 | 45.841 | 45.508 | 45.174 | 44.841 | 44.507 | 44.174 | 43.840 | 43.507 |

TABLE C-3. (C ontinued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 44.256 | 43.934 | 43.611 | 43.287 | 42.964 | 42.640 | 42.316 | 41.993 | 41.669 |
| 42.188 | 41.876 | 41.563 | 41.251 | 40.939 | 40.627 | 40.315 | 40.002 | 39.690 |
| 40.472 | 40.169 | 39.866 | 39.562 | 39.259 | 38.956 | 38.653 | 38.349 | 36.046 |
| 38.786 | 38.491 | 38.197 | 37.903 | 37.609 | 37.314 | 37.020 | 36.726 | 36.431 |
| 37.719 | 37.430 | 37.140 | 36.850 | 36.560 | 36.270 | 35.980 | 35.691 | 35.401 |
| 36.040 | 35.759 | 35.478 | 35.198 | 34.917 | 34.637 | 34.356 | 34.076 | 32.795 |

**ELECTRODE TEMPERATURE DISTRIBUTION**
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 35.953
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 50.734 | 50.388 | 50.043 | 49.697 | 49.352 | 49.006 | 48.660 | 48.315 | 47.969 |
| 50.107 | 49.761 | 49.416 | 49.071 | 48.726 | 48.380 | 48.035 | 47.690 | 47.345 |
| 43.142 | 42.842 | 42.541 | 42.240 | 41.939 | 41.639 | 41.338 | 41.037 | 40.737 |
| 40.631 | 40.344 | 40.058 | 39.771 | 39.485 | 39.198 | 38.912 | 38.625 | 38.339 |
| 38.777 | 38.500 | 38.223 | 37.947 | 37.670 | 37.393 | 37.116 | 36.840 | 36.563 |
| 36.989 | 36.722 | 36.455 | 36.188 | 35.921 | 35.654 | 35.387 | 35.119 | 34.851 |
| 35.291 | 35.033 | 34.775 | 34.517 | 34.259 | 34.001 | 33.743 | 33.485 | 33.227 |
| 33.460 | 33.212 | 32.964 | 32.717 | 32.469 | 32.222 | 31.974 | 31.726 | 31.479 |
| 31.958 | 31.718 | 31.479 | 31.239 | 31.000 | 30.760 | 30.521 | 30.282 | 30.042 |
| 30.487 | 30.256 | 30.024 | 29.793 | 29.562 | 29.331 | 29.099 | 28.868 | 28.637 |
| 29.581 | 29.354 | 29.126 | 28.899 | 28.672 | 28.445 | 28.217 | 27.990 | 27.763 |
| 28.124 | 27.905 | 27.686 | 27.467 | 27.248 | 27.029 | 26.811 | 26.592 | 26.373 |

**ELECTRODE TEMPERATURE DISTRIBUTION**
STARTING TIME =480.00
ENDING TIME =510.00
AVERAGE TEMPERATURE = 28.519
PRESURE= 0.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 41.544 | 41.261 | 40.978 | 40.695 | 40.412 | 40.129 | 39.846 | 39.563 | 39.280 |
| 41.024 | 40.742 | 40.459 | 40.176 | 39.894 | 39.611 | 39.328 | 39.046 | 38.763 |

TABLE C-3. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 34.623 | 34.362 | 34.140 | 33.899 | 33.658 | 33.416 | 33.175 | 32.934 | 32.692 |
| 32.407 | 32.179 | 31.950 | 31.722 | 31.493 | 31.265 | 31.036 | 30.807 | 30.579 |
| 30.777 | 30.558 | 30.338 | 30.118 | 29.899 | 29.679 | 29.460 | 29.240 | 29.020 |
| 29.214 | 29.003 | 28.792 | 28.581 | 28.370 | 28.159 | 27.948 | 27.737 | 27.526 |
| 27.737 | 27.534 | 27.331 | 27.128 | 26.926 | 26.723 | 26.520 | 26.317 | 26.115 |
| 26.146 | 25.953 | 25.759 | 25.566 | 25.372 | 25.179 | 24.985 | 24.792 | 24.598 |
| 24.855 | 24.669 | 24.483 | 24.297 | 24.110 | 23.924 | 23.738 | 23.552 | 23.365 |
| 23.597 | 23.418 | 23.243 | 23.060 | 22.881 | 22.702 | 22.523 | 22.344 | 22.165 |
| 22.840 | 22.664 | 22.489 | 22.313 | 22.138 | 21.962 | 21.787 | 21.611 | 21.435 |
| 21.600 | 21.432 | 21.264 | 21.096 | 20.928 | 20.760 | 20.591 | 20.423 | 20.255 |

TABLE C-4. Example of Temperature Distribution During Shut-Down Process with Oil Coolant (P=0 KPa, Re=15).

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =120.00
ENDING TIME =150.00
AVERAGE TEMPERATURE =187.700
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 208.054 | 206.920 | 205.786 | 204.652 | 203.518 | 202.385 | 201.251 | 200.117 | 198.983 |
| 205.779 | 204.645 | 203.511 | 202.377 | 201.243 | 200.110 | 198.976 | 197.842 | 196.708 |
| 202.634 | 201.505 | 200.376 | 199.247 | 198.118 | 196.989 | 195.860 | 194.732 | 193.603 |
| 199.932 | 198.805 | 197.679 | 196.553 | 195.426 | 194.300 | 193.173 | 192.047 | 190.921 |
| 197.437 | 196.312 | 195.187 | 194.062 | 192.937 | 191.812 | 190.687 | 189.562 | 188.437 |
| 194.946 | 193.822 | 192.699 | 191.575 | 190.452 | 189.328 | 188.204 | 187.081 | 185.957 |
| 192.463 | 191.341 | 190.219 | 189.096 | 187.974 | 186.852 | 185.730 | 184.607 | 183.485 |
| 189.945 | 188.824 | 187.704 | 186.583 | 185.462 | 184.342 | 183.221 | 182.101 | 180.980 |
| 187.483 | 186.364 | 185.244 | 184.125 | 183.006 | 181.887 | 180.767 | 179.648 | 178.529 |
| 185.020 | 183.902 | 182.784 | 181.666 | 180.548 | 179.430 | 178.312 | 177.194 | 176.077 |
| 182.672 | 181.555 | 180.438 | 179.321 | 178.203 | 177.086 | 175.969 | 174.852 | 173.734 |
| 180.200 | 179.084 | 177.968 | 176.852 | 175.737 | 174.621 | 173.505 | 172.389 | 171.274 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =150.00
ENDING TIME =180.00
AVERAGE TEMPERATURE =173.345
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 194.247 | 193.188 | 192.130 | 191.071 | 190.013 | 188.954 | 187.895 | 186.837 | 185.778 |
| 192.114 | 191.056 | 189.997 | 188.939 | 187.880 | 186.822 | 185.763 | 184.705 | 183.646 |
| 188.117 | 187.069 | 186.021 | 184.973 | 183.925 | 182.877 | 181.829 | 180.781 | 179.733 |
| 185.136 | 184.093 | 183.050 | 182.007 | 180.964 | 179.921 | 178.878 | 177.835 | 176.792 |
| 182.546 | 181.506 | 180.466 | 179.426 | 178.386 | 177.346 | 176.305 | 175.265 | 174.225 |
| 179.965 | 178.928 | 177.890 | 176.853 | 175.816 | 174.779 | 173.741 | 172.704 | 171.667 |
| 177.401 | 176.367 | 175.332 | 174.298 | 173.264 | 172.229 | 171.195 | 170.160 | 169.126 |
| 174.765 | 173.734 | 172.703 | 171.672 | 170.641 | 169.610 | 168.579 | 167.548 | 166.517 |

TABLE C-4. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 172.247 | 171.218 | 170.190 | 169.162 | 168.133 | 167.105 | 166.077 | 165.048 | 164.020 |
| 169.727 | 168.701 | 167.675 | 166.650 | 165.624 | 164.599 | 163.573 | 162.548 | 161.522 |
| 167.445 | 166.421 | 165.396 | 164.372 | 163.348 | 162.324 | 161.300 | 160.276 | 159.252 |
| 164.906 | 163.885 | 162.864 | 161.843 | 160.822 | 159.801 | 158.779 | 157.758 | 156.737 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =180.00
ENDING TIME =210.00
AVERAGE TEMPERATURE =157.852
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 179.207 | 178.230 | 177.253 | 176.277 | 175.300 | 174.324 | 173.347 | 172.370 | 171.394 |
| 177.229 | 176.253 | 175.276 | 174.300 | 173.324 | 172.347 | 171.371 | 170.394 | 169.418 |
| 172.342 | 171.382 | 170.422 | 169.462 | 168.502 | 167.542 | 166.582 | 165.622 | 164.661 |
| 169.124 | 168.172 | 167.219 | 166.266 | 165.313 | 164.360 | 163.408 | 162.455 | 161.502 |
| 166.453 | 165.505 | 164.556 | 163.608 | 162.659 | 161.711 | 160.762 | 159.814 | 158.865 |
| 163.795 | 162.851 | 161.907 | 160.963 | 160.019 | 159.075 | 158.131 | 157.187 | 156.243 |
| 161.166 | 160.226 | 159.286 | 158.346 | 157.407 | 156.467 | 155.527 | 154.587 | 153.648 |
| 158.428 | 157.494 | 156.559 | 155.624 | 154.690 | 153.755 | 152.820 | 151.886 | 150.951 |
| 155.870 | 154.940 | 154.009 | 153.078 | 152.148 | 151.217 | 150.287 | 149.356 | 148.426 |
| 153.311 | 152.384 | 151.458 | 150.532 | 149.605 | 148.679 | 147.752 | 146.826 | 145.900 |
| 151.111 | 150.186 | 149.262 | 148.338 | 147.414 | 146.490 | 145.565 | 144.641 | 143.717 |
| 148.525 | 147.606 | 146.686 | 145.766 | 144.847 | 143.927 | 143.007 | 142.088 | 141.168 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =210.00
ENDING TIME =240.00
AVERAGE TEMPERATURE =141.741
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 163.371 | 162.481 | 161.590 | 160.700 | 159.810 | 158.919 | 158.029 | 157.139 | 156.249 |
| 161.558 | 160.668 | 159.778 | 158.888 | 157.998 | 157.108 | 156.218 | 155.327 | 154.437 |
| 155.814 | 154.946 | 154.078 | 153.210 | 152.342 | 151.474 | 150.606 | 149.738 | 148.870 |
| 152.416 | 151.557 | 150.698 | 149.840 | 148.981 | 148.122 | 147.264 | 146.405 | 145.546 |

TABLE C-4. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 149.687 | 148.834 | 147.981 | 147.128 | 146.276 | 145.423 | 144.570 | 143.717 | 142.864 |
| 146.979 | 146.132 | 145.285 | 144.437 | 143.590 | 142.743 | 141.896 | 141.049 | 140.202 |
| 144.310 | 143.468 | 142.527 | 141.785 | 140.944 | 140.102 | 139.261 | 138.420 | 137.579 |
| 141.502 | 140.667 | 139.832 | 138.997 | 138.162 | 137.328 | 136.493 | 135.658 | 134.823 |
| 138.931 | 138.101 | 137.272 | 136.442 | 135.613 | 134.783 | 133.954 | 133.124 | 132.295 |
| 136.360 | 135.536 | 134.712 | 133.888 | 133.064 | 132.240 | 131.416 | 130.592 | 129.768 |
| 134.259 | 133.438 | 132.617 | 131.796 | 130.975 | 130.153 | 129.332 | 128.511 | 127.690 |
| 131.658 | 130.842 | 130.027 | 129.212 | 128.397 | 127.581 | 126.766 | 125.951 | 125.136 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =240.00
ENDING TIME =270.00
AVERAGE TEMPERATURE =125.505
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 147.169 | 146.367 | 145.565 | 144.763 | 143.961 | 143.159 | 142.357 | 141.555 | 140.753 |
| 145.526 | 144.724 | 143.922 | 143.120 | 142.319 | 141.517 | 140.715 | 139.913 | 139.111 |
| 139.018 | 138.244 | 137.469 | 136.695 | 135.920 | 135.146 | 134.371 | 133.597 | 132.822 |
| 135.506 | 134.743 | 133.980 | 133.216 | 132.453 | 131.689 | 130.926 | 130.162 | 129.399 |
| 132.755 | 131.999 | 131.242 | 130.486 | 129.729 | 128.973 | 128.217 | 127.460 | 126.704 |
| 130.031 | 129.282 | 128.532 | 127.783 | 127.034 | 126.284 | 125.535 | 124.785 | 124.036 |
| 127.358 | 126.615 | 125.873 | 125.130 | 124.387 | 123.645 | 122.902 | 122.160 | 121.417 |
| 124.521 | 123.786 | 123.051 | 122.317 | 121.582 | 120.847 | 120.113 | 119.378 | 118.644 |
| 121.971 | 121.243 | 120.514 | 119.786 | 119.058 | 118.330 | 117.602 | 116.873 | 116.145 |
| 119.424 | 118.702 | 117.981 | 117.259 | 116.537 | 115.816 | 115.094 | 114.373 | 113.651 |
| 117.440 | 116.722 | 116.004 | 115.286 | 114.567 | 113.849 | 113.131 | 112.412 | 111.694 |
| 114.861 | 114.150 | 113.439 | 112.727 | 112.016 | 111.305 | 110.594 | 109.883 | 109.171 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =270.00
ENDING TIME =300.00
AVERAGE TEMPERATURE =109.588
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

TABLE C-4. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 131.003 | 130.289 | 129.575 | 128.861 | 128.147 | 127.433 | 126.719 | 126.005 | 125.291 |
| 129.529 | 128.816 | 128.102 | 127.388 | 126.675 | 125.961 | 125.247 | 124.534 | 123.820 |
| 122.401 | 121.719 | 121.037 | 120.355 | 119.673 | 118.991 | 118.310 | 117.628 | 116.946 |
| 118.849 | 118.180 | 117.510 | 116.841 | 116.171 | 115.501 | 114.832 | 114.162 | 113.493 |
| 116.116 | 115.455 | 114.793 | 114.131 | 113.470 | 112.808 | 112.146 | 111.485 | 110.823 |
| 113.418 | 112.764 | 112.110 | 111.457 | 110.803 | 110.149 | 109.496 | 108.842 | 108.188 |
| 110.780 | 110.135 | 109.489 | 108.843 | 108.197 | 107.551 | 106.905 | 106.259 | 105.613 |
| 107.962 | 107.325 | 106.688 | 106.051 | 105.414 | 104.777 | 104.140 | 103.504 | 102.867 |
| 105.472 | 104.842 | 104.213 | 103.583 | 102.953 | 102.323 | 101.694 | 101.064 | 100.434 |
| 102.988 | 102.366 | 101.744 | 101.121 | 100.499 | 99.877 | 99.255 | 98.632 | 98.010 |
| 101.138 | 100.520 | 99.901 | 99.283 | 98.664 | 98.046 | 97.427 | 96.808 | 96.190 |
| 98.624 | 98.013 | 97.402 | 96.792 | 96.181 | 95.570 | 94.960 | 94.349 | 93.738 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =300.00
ENDING TIME =330.00
AVERAGE TEMPERATURE = 94.368
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 115.230 | 114.602 | 113.974 | 113.346 | 112.718 | 112.090 | 111.462 | 110.834 | 110.206 |
| 113.923 | 113.296 | 112.668 | 112.040 | 111.413 | 110.785 | 110.157 | 109.530 | 108.902 |
| 106.353 | 105.760 | 105.168 | 104.575 | 103.983 | 103.390 | 102.798 | 102.205 | 101.613 |
| 102.835 | 102.256 | 101.676 | 101.097 | 100.518 | 99.938 | 99.359 | 98.780 | 98.200 |
| 100.163 | 99.592 | 99.022 | 98.451 | 97.880 | 97.310 | 96.739 | 96.168 | 95.597 |
| 97.534 | 96.972 | 96.409 | 95.847 | 95.285 | 94.723 | 94.161 | 93.599 | 93.036 |
| 94.975 | 94.421 | 93.867 | 93.313 | 92.759 | 92.206 | 91.652 | 91.098 | 90.544 |
| 92.226 | 91.682 | 91.138 | 90.593 | 90.049 | 89.505 | 88.961 | 88.417 | 87.873 |
| 89.834 | 89.298 | 88.761 | 88.225 | 87.689 | 87.152 | 86.616 | 86.080 | 85.543 |
| 87.453 | 86.925 | 86.396 | 85.868 | 85.340 | 84.811 | 84.283 | 83.754 | 83.226 |
| 85.751 | 85.227 | 84.702 | 84.178 | 83.653 | 83.129 | 82.604 | 82.080 | 81.555 |
| 83.344 | 82.828 | 82.311 | 81.795 | 81.279 | 80.763 | 80.247 | 79.731 | 79.215 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =330.00

TABLE C-4. (Continued).

ENDING TIME =360.00
AVERAGE TEMPERATURE = 80.144
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 100.154 | 99.608 | 99.063 | 98.517 | 97.971 | 97.425 | 96.879 | 96.334 | 95.788 |
| 99.009 | 98.464 | 97.918 | 97.373 | 96.827 | 96.282 | 95.736 | 95.191 | 94.545 |
| 91.193 | 90.685 | 90.177 | 89.669 | 89.161 | 88.653 | 88.145 | 87.637 | 87.129 |
| 87.779 | 87.285 | 86.790 | 86.296 | 85.801 | 85.307 | 84.812 | 84.318 | 83.823 |
| 85.211 | 84.725 | 84.240 | 83.755 | 83.269 | 82.784 | 82.298 | 81.813 | 81.327 |
| 82.693 | 82.216 | 81.740 | 81.263 | 80.786 | 80.310 | 79.833 | 79.357 | 76.880 |
| 80.253 | 79.785 | 79.317 | 78.849 | 78.381 | 77.913 | 77.445 | 76.977 | 76.509 |
| 77.622 | 77.164 | 76.706 | 76.248 | 75.790 | 75.332 | 74.874 | 74.416 | 73.958 |
| 75.365 | 74.915 | 74.465 | 74.015 | 73.565 | 73.115 | 72.665 | 72.215 | 71.765 |
| 73.123 | 72.681 | 72.240 | 71.798 | 71.356 | 70.914 | 70.472 | 70.030 | 69.589 |
| 71.580 | 71.142 | 70.704 | 70.266 | 69.828 | 69.391 | 68.953 | 68.515 | 68.077 |
| 69.318 | 68.889 | 68.459 | 68.030 | 67.601 | 67.172 | 66.742 | 66.313 | 65.884 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =360.00
ENDING TIME =390.00
AVERAGE TEMPERATURE = 67.130
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 86.019 | 85.550 | 85.082 | 84.613 | 84.144 | 83.675 | 83.207 | 82.738 | 82.269 |
| 85.026 | 84.558 | 84.090 | 83.621 | 83.153 | 82.684 | 82.216 | 81.747 | 81.279 |
| 77.165 | 76.736 | 76.306 | 75.876 | 75.446 | 75.016 | 74.586 | 74.156 | 73 726 |
| 73.918 | 73.502 | 73.085 | 72.669 | 72.252 | 71.836 | 71.419 | 71.003 | 70.587 |
| 71.493 | 71.085 | 70.678 | 70.271 | 69.863 | 69.456 | 69.048 | 68.641 | 68.234 |
| 69.123 | 68.724 | 68.326 | 67.928 | 67.529 | 67.131 | 66.732 | 66.334 | 65.936 |
| 66.837 | 66.447 | 66.058 | 65.668 | 65.278 | 64.888 | 64.499 | 64.109 | 63.719 |
| 64.367 | 63.988 | 63.608 | 63.228 | 62.848 | 62.469 | 62.089 | 61.709 | 61.329 |
| 62.276 | 61.904 | 61.532 | 61.160 | 60.788 | 60.417 | 60.045 | 59.673 | 59.301 |
| 60.204 | 59.840 | 59.477 | 59.113 | 58.749 | 58.385 | 58.022 | 57.658 | 57.294 |

TABLE C-4. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 58.825 | 58.465 | 58.106 | 57.746 | 57.386 | 57.026 | 56.666 | 56.307 | 55.947 |
| 56.741 | 56.390 | 56.038 | 55.687 | 55.336 | 54.984 | 54.633 | 54.282 | 53.930 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =390.00
ENDING TIME =420.00
AVERAGE TEMPERATURE = 55.463
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 73.003 | 72.605 | 72.208 | 71.810 | 71.412 | 71.014 | 70.616 | 70.218 | 69.821 |
| 72.152 | 71.755 | 71.357 | 70.960 | 70.562 | 70.165 | 69.767 | 69.370 | 68.972 |
| 64.437 | 64.078 | 63.719 | 63.360 | 63.001 | 62.642 | 62.283 | 61.924 | 61.565 |
| 61.407 | 61.061 | 60.715 | 60.369 | 60.023 | 59.677 | 59.331 | 58.985 | 58.639 |
| 59.156 | 58.819 | 58.482 | 58.145 | 57.808 | 57.471 | 57.134 | 56.797 | 56.459 |
| 56.966 | 56.638 | 56.309 | 55.981 | 55.653 | 55.324 | 54.996 | 54.668 | 54.339 |
| 54.863 | 54.544 | 54.224 | 53.904 | 53.584 | 53.264 | 52.944 | 52.624 | 52.304 |
| 52.590 | 52.279 | 51.969 | 51.659 | 51.348 | 51.038 | 50.728 | 50.418 | 50.107 |
| 50.686 | 50.384 | 50.081 | 49.779 | 49.476 | 49.173 | 48.871 | 48.568 | 48.266 |
| 48.806 | 48.513 | 48.218 | 47.923 | 47.628 | 47.333 | 47.038 | 46.743 | 46.445 |
| 47.595 | 47.304 | 47.013 | 46.722 | 46.431 | 46.139 | 45.849 | 45.557 | 45.256 |
| 45.712 | 45.429 | 45.146 | 44.863 | 44.580 | 44.297 | 44.014 | 43.731 | 43.448 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =420.00
ENDING TIME =450.00
AVERAGE TEMPERATURE = 45.201
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 61.222 | 60.889 | 60.555 | 60.221 | 59.888 | 59.554 | 59.221 | 58.887 | 58.553 |
| 60.501 | 60.168 | 59.835 | 59.501 | 59.168 | 58.834 | 58.501 | 58.168 | 57.834 |
| 53.100 | 52.804 | 52.509 | 52.213 | 51.917 | 51.621 | 51.325 | 51.029 | 50.734 |
| 50.326 | 50.042 | 49.759 | 49.475 | 49.191 | 48.908 | 48.624 | 48.341 | 48.057 |
| 48.274 | 47.999 | 47.724 | 47.449 | 47.173 | 46.898 | 46.623 | 46.348 | 46.073 |
| 46.286 | 46.019 | 45.752 | 45.485 | 45.219 | 44.952 | 44.685 | 44.418 | 44.152 |

TABLE C-4. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 44.387 | 44 128 | 43.869 | 43.611 | 43.352 | 43.093 | 42.834 | 42.575 | 42.31[illegible] |
| 42.333 | 42.084 | 41.834 | 41.584 | 41.334 | 41.085 | 40.835 | 40.585 | 40.33[illegible] |
| 40.634 | 40.391 | 40.149 | 39.906 | 39.663 | 39.421 | 39.178 | 36.936 | 38.69[illegible] |
| 38.962 | 38.727 | 38.491 | 38.256 | 38.021 | 37.785 | 37.550 | 37.314 | 37.079 |
| 37.913 | 37.681 | 37.449 | 37.217 | 36.985 | 36.753 | 36.521 | 36.290 | 36.058 |
| 36.245 | 36.021 | 35.796 | 35.572 | 35.348 | 35.123 | 34.899 | 34.674 | 34.450 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =450.00
ENDING TIME =480.00
AVERAGE TEMPERATURE = 36.340
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 50.734 | 50.458 | 50.181 | 49.905 | 49.628 | 49.352 | 49.075 | 48.799 | 48.522 |
| 50.130 | 49.853 | 49.577 | 49.301 | 49.025 | 48.749 | 48.472 | 48.196 | 47.922 |
| 43.182 | 42.942 | 42.701 | 42.461 | 42.220 | 41.980 | 41.739 | 41.498 | 41.258 |
| 40.688 | 40.459 | 40.230 | 40.000 | 39.771 | 39.542 | 39.313 | 39.084 | 38.854 |
| 38.851 | 38.629 | 38.408 | 38.186 | 37.965 | 37.744 | 37.522 | 37.301 | 37.080 |
| 37.078 | 36.865 | 36.651 | 36.437 | 36.224 | 36.010 | 35.796 | 35.582 | 35.369 |
| 35.394 | 35.188 | 34.982 | 34.775 | 34.569 | 34.363 | 34.156 | 33.950 | 33.741 |
| 33.575 | 33.377 | 33.179 | 32.981 | 32.783 | 32.585 | 32.387 | 32.189 | 31.990 |
| 32.085 | 31.894 | 31.702 | 31.511 | 31.319 | 31.128 | 30.936 | 30.744 | 30.553 |
| 30.626 | 30.441 | 30.256 | 30.071 | 29.886 | 29.701 | 29.516 | 29.331 | 29.145 |
| 29.733 | 29.551 | 29.369 | 29.187 | 29.005 | 28.823 | 28.642 | 28.460 | 28.278 |
| 28.285 | 28.109 | 27.934 | 27.759 | 27.584 | 27.409 | 27.234 | 27.059 | 26.884 |

ELECTRODE TEMPERATURE DISTRIBUTION
STARTING TIME =480.00
ENDING TIME =510.00
AVERAGE TEMPERATURE = 28.825
PRESURE= 3500.0 KPa
REYNOLD'S NUMBER= 0.15000E+02
COOLANT:OIL

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 41.544 | 41.318 | 41.091 | 40.865 | 40.639 | 40.412 | 40.186 | 39.959 | 39.733 |
| 41.043 | 40.817 | 40.591 | 40.365 | 40.139 | 39.913 | 39.686 | 39.460 | 39.234 |

TABLE C-4. (Continued).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 34.655 | 34.462 | 34.269 | 34.076 | 33.883 | 33.690 | 33.497 | 33.304 | 33.111 |
| 32.453 | 32.270 | 32.087 | 31.904 | 31.722 | 31.539 | 31.356 | 31.173 | 30.990 |
| 30.836 | 30.660 | 30.485 | 30.309 | 30.133 | 29.957 | 29.782 | 29.606 | 29.430 |
| 29.284 | 29.115 | 28.947 | 28.778 | 28.609 | 28.440 | 28.272 | 28.103 | 27.934 |
| 27.818 | 27.656 | 27.493 | 27.331 | 27.169 | 27.007 | 26.845 | 26.682 | 26.520 |
| 26.236 | 26.082 | 25.927 | 25.772 | 25.617 | 25.462 | 25.308 | 25.153 | 24.998 |
| 24.955 | 24.806 | 24.657 | 24.508 | 24.359 | 24.210 | 24.061 | 23.912 | 23.763 |
| 23.704 | 23.561 | 23.418 | 23.275 | 23.131 | 22.988 | 22.845 | 22.702 | 22.558 |
| 22.957 | 22.816 | 22.676 | 22.535 | 22.395 | 22.255 | 22.114 | 21.974 | 21.833 |
| 21.724 | 21.589 | 21.455 | 21.320 | 21.186 | 21.051 | 20.916 | 20.782 | 20.647 |

# APPENDIX D

## CURRENT DENSITY DISTRIBUTION DURING SHUT-DOWN PROCESS FOR:

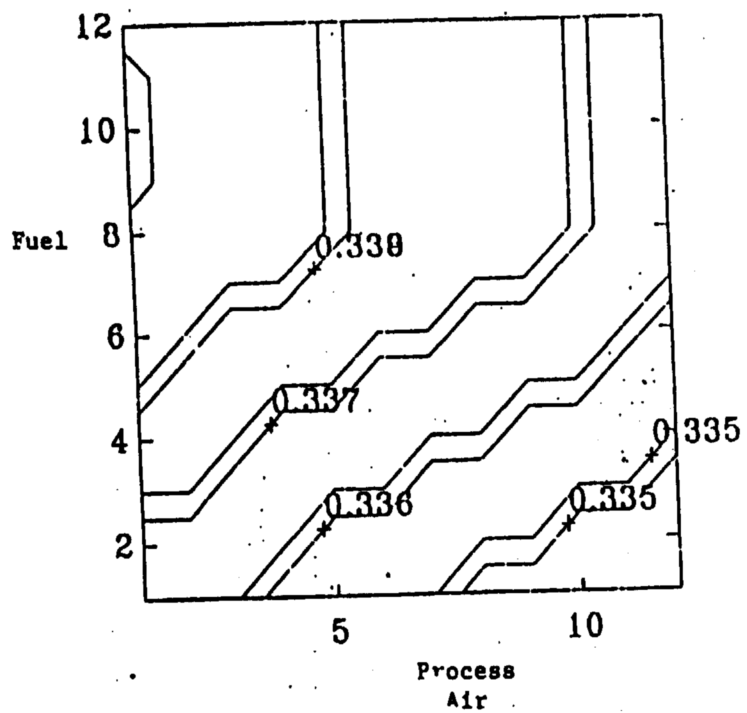
(D-1) THROUGH (D-13): WATER COOLANT
(P=3500 KPa, Re = 1250)

(D-14) THROUGH (D-26): WATER COOLANT
(P=0 KPa, Re = 1250)

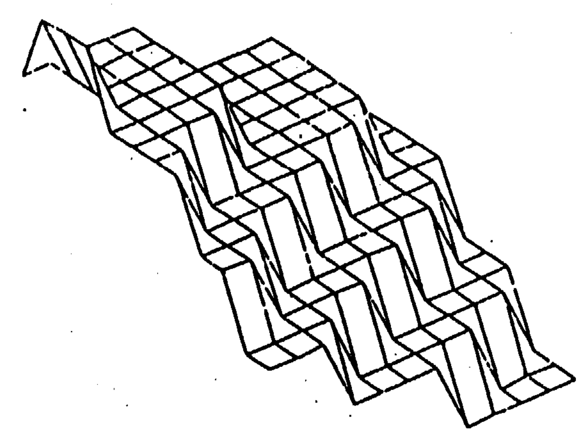
(D-27) THROUGH (D-39): WATER COOLANT
(P=0 KPa, Re = 6167)

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

COOLING FLUID: WATER

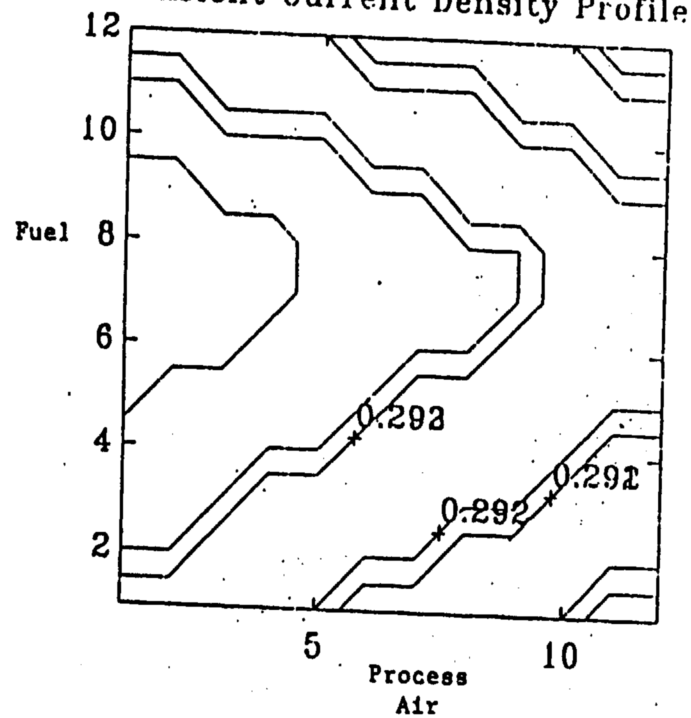
SHUT-DOWN PROCESS

TIME INTERVAL NO.1

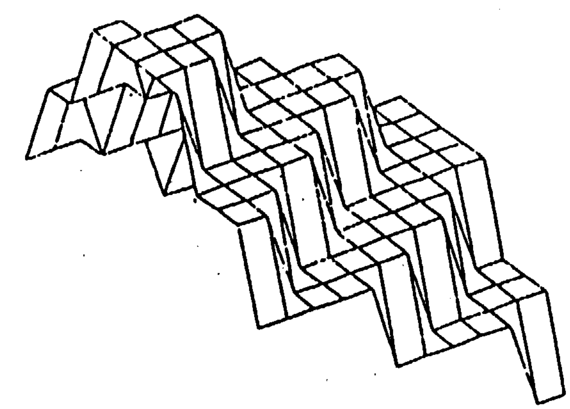
TABLE D-1. Transient Current Density Distribution During a Shut-Down Prcess (Water Coolant, P=3500 KPa, Re = 1250, T.I. = 1).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

COOLING FLUID: WATER

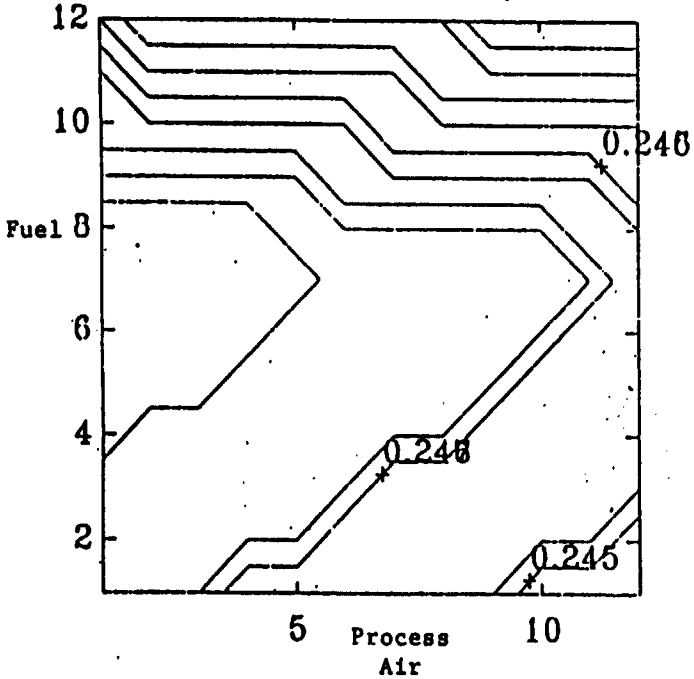
SHUT-DOWN PROCESS

TIME INTERVAL NO.2

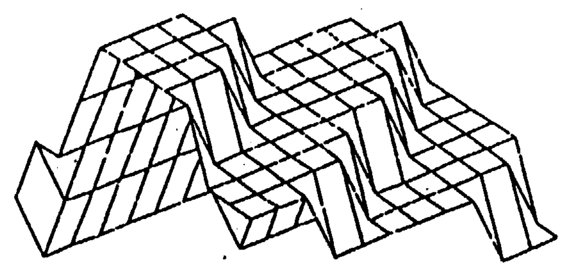
TABLE D-2. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 2).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

COOLING FLUID: WATER

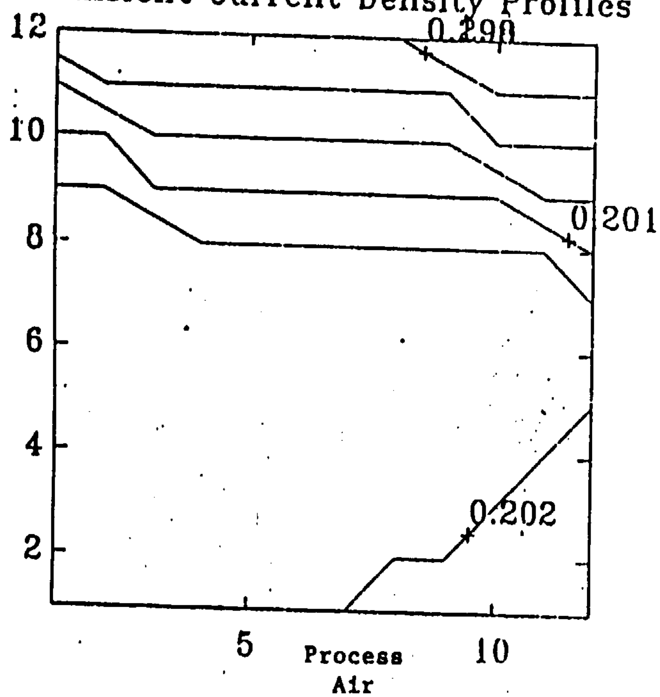
SHUT-DOWN PROCESS

TIME INTERVAL NO.3

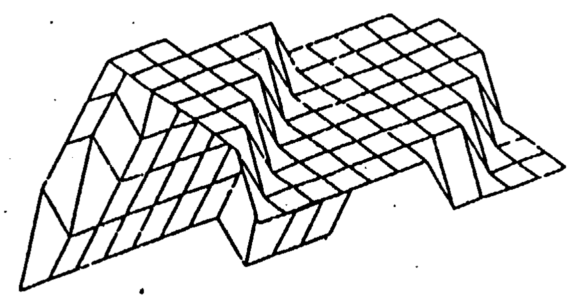
TABLE D-3. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 3).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

COOLING FLUID: WATER

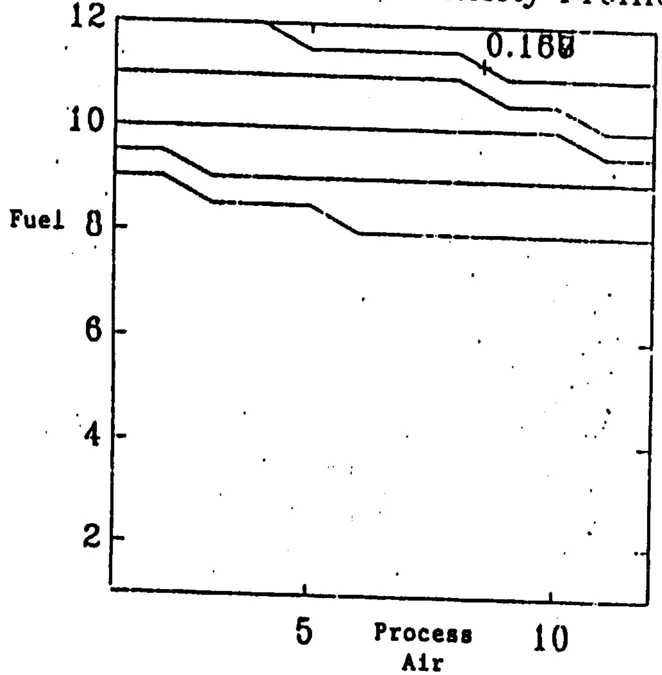
SHUT-DOWN PROCESS

TIME INTERVAL NO.4

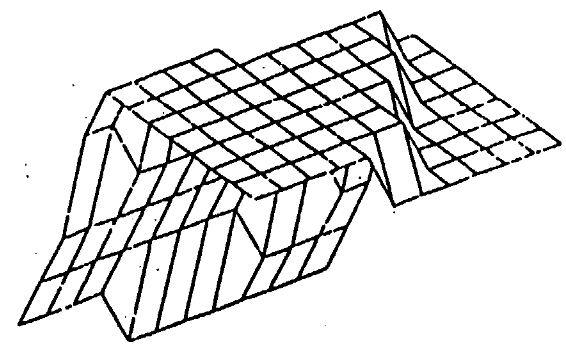
TABLE D-4. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500, KPa, Re = 1250, T.I. = 4).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

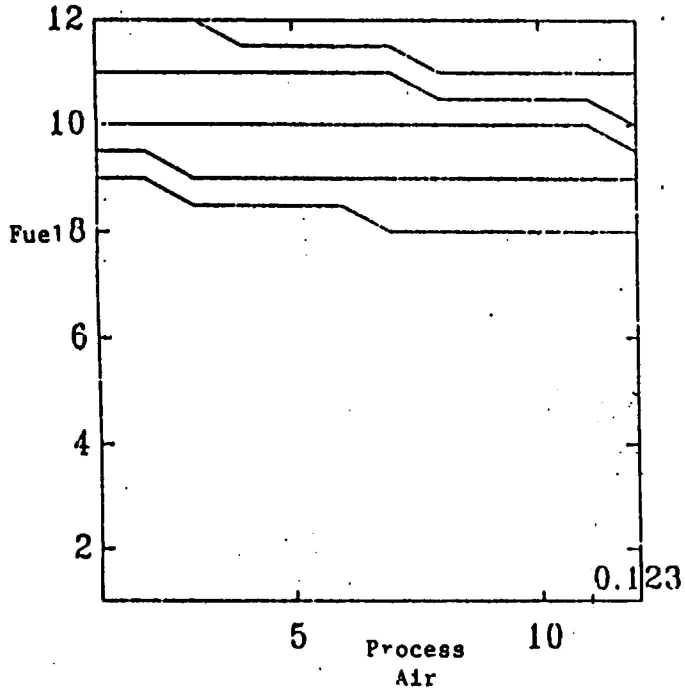
COOLING FLUID: WATER

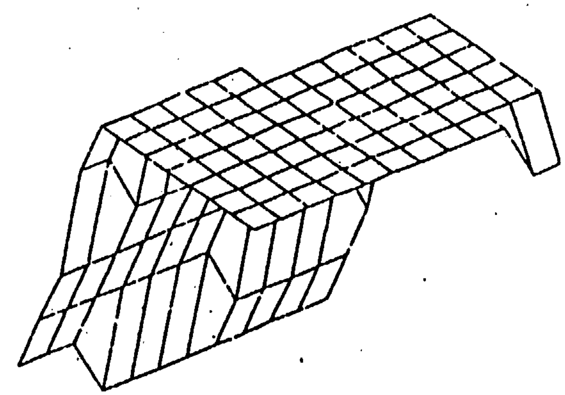
SHUT-DOWN PROCESS

TIME INTERVAL NO.5

TABLE D-5. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 5).

## TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

COOLING FLUID: WATER

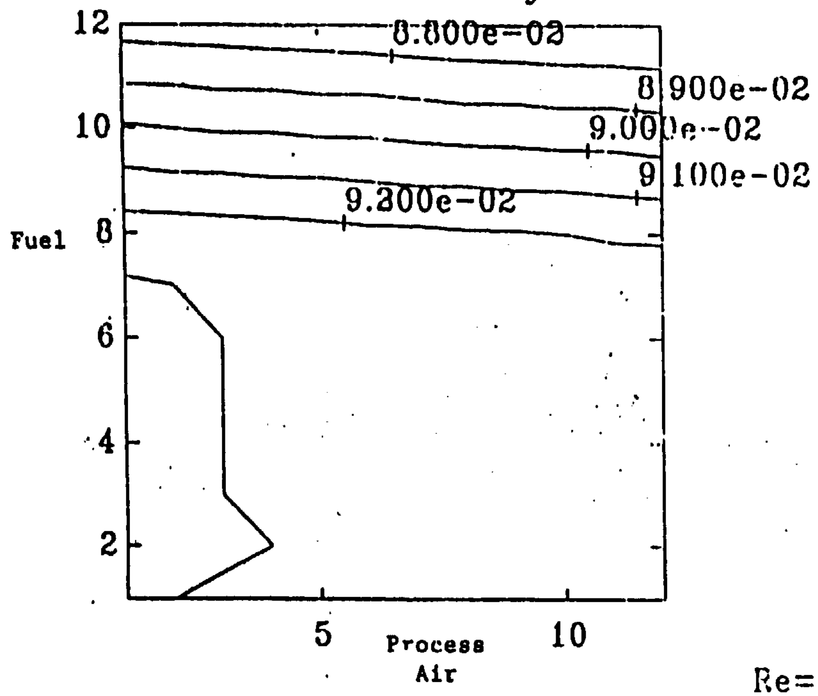
SHUT-DOWN PROCESS

TIME INTERVAL NO:6

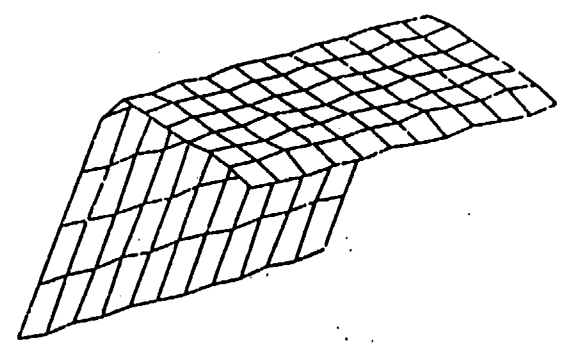
TABLE D-6. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 6).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

COOLING FLUID: WATER

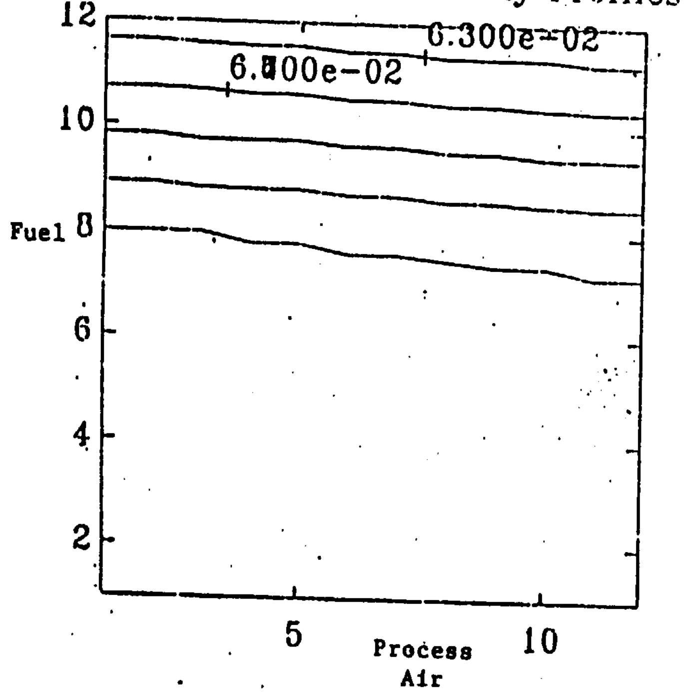
SHUT-DOWN PROCESS

TIME INTERVAL NO.7

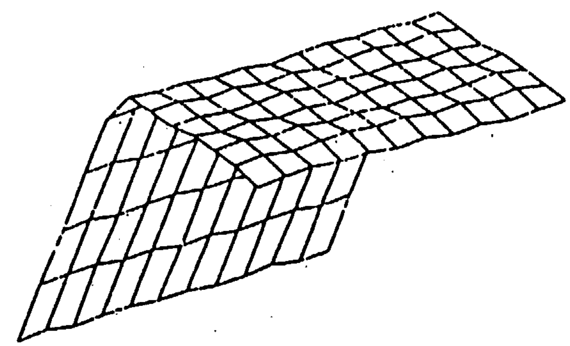
TABLE D-7. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 7).

# TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

COOLING FLUID: WATER

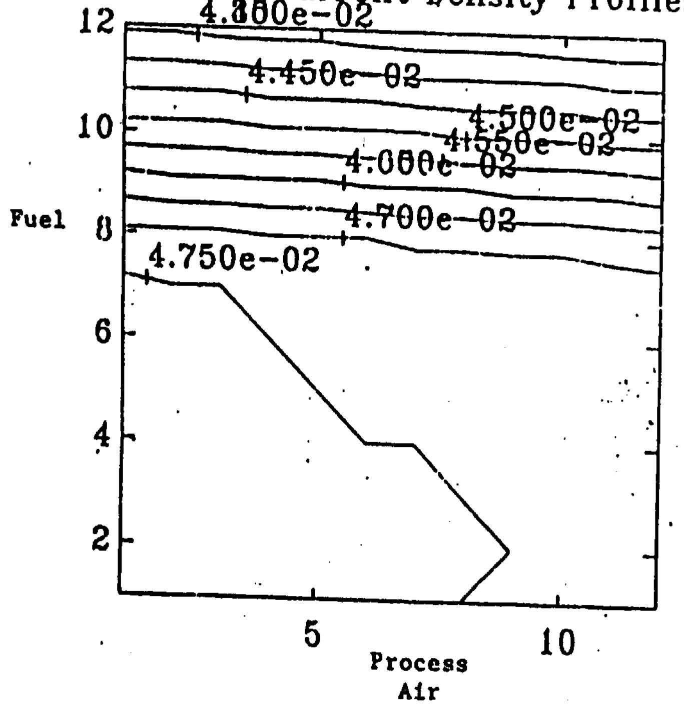
SHUT-DOWN PROCESS

TIME INTERVAL NO.8.

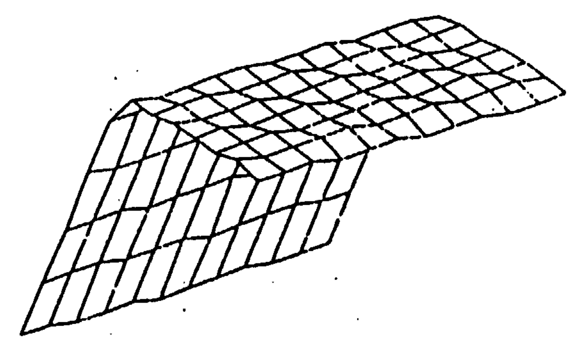
TABLE D-8. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 8).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=3500 KPa

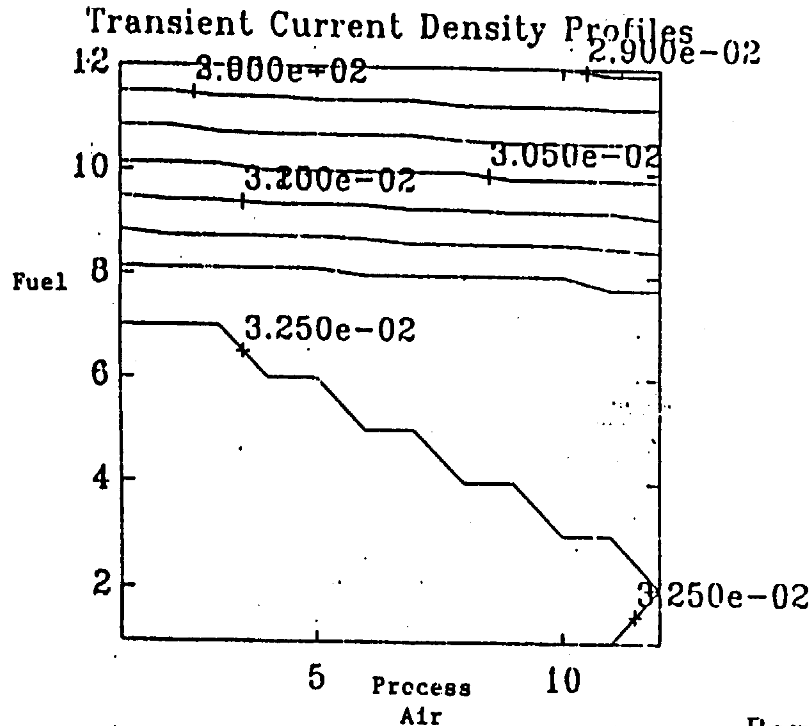
COOLING FLUID: WATER

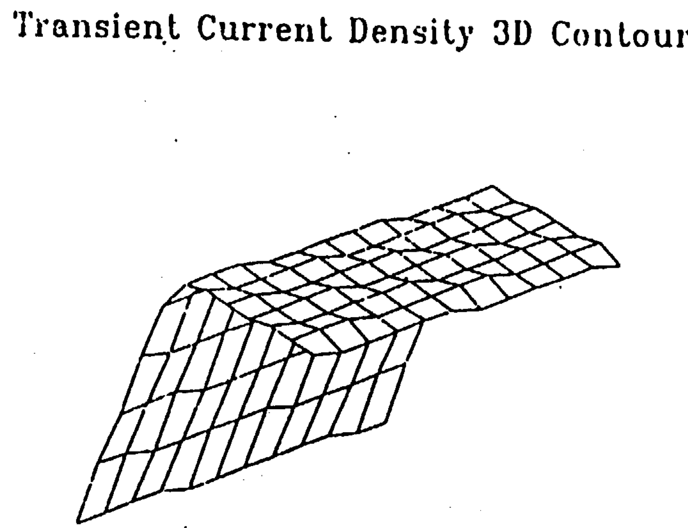
SHUT-DOWN PROCESS

TIME INTERVAL NO.9

TABLE D-9. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 9).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

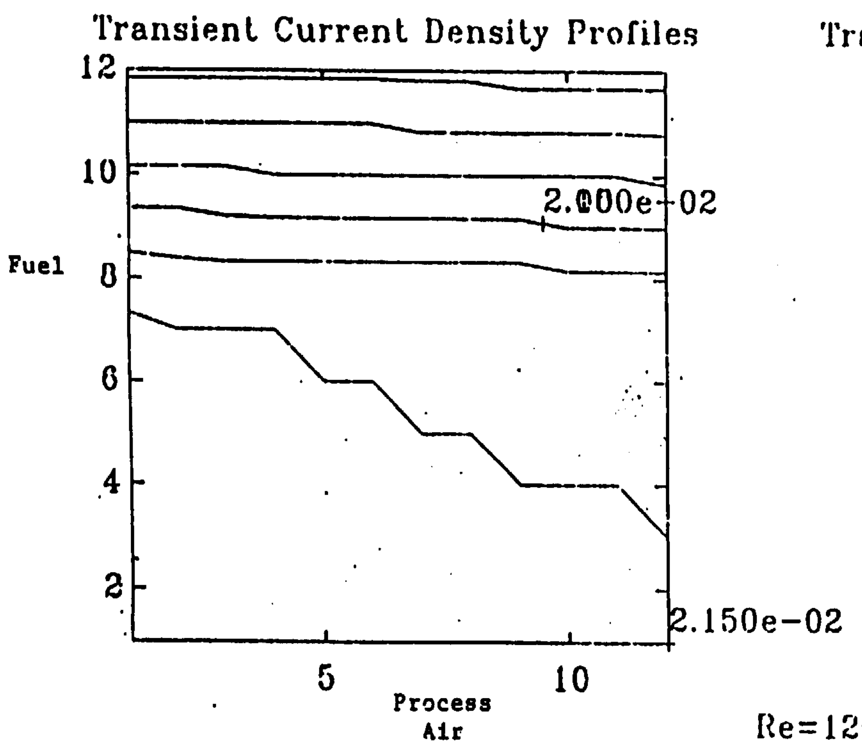
COOLING FLUID: WATER

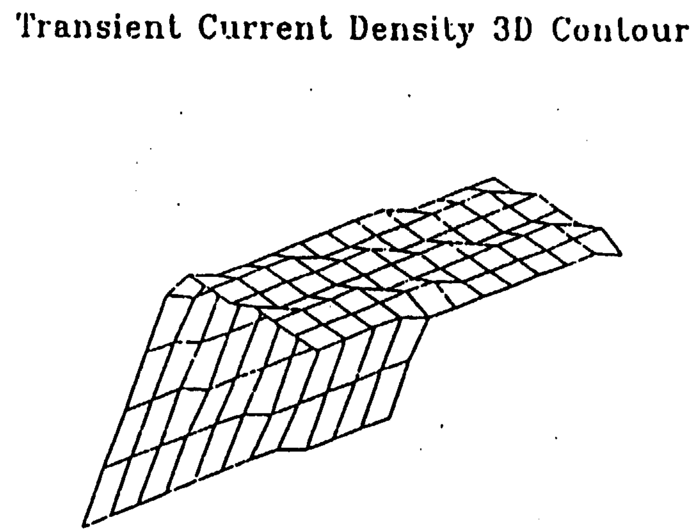
SHUT-DOWN PROCESS

TIME INTERVAL NO.10

TABLE D-10. Transient Current Density Distribution DUring a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 10).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

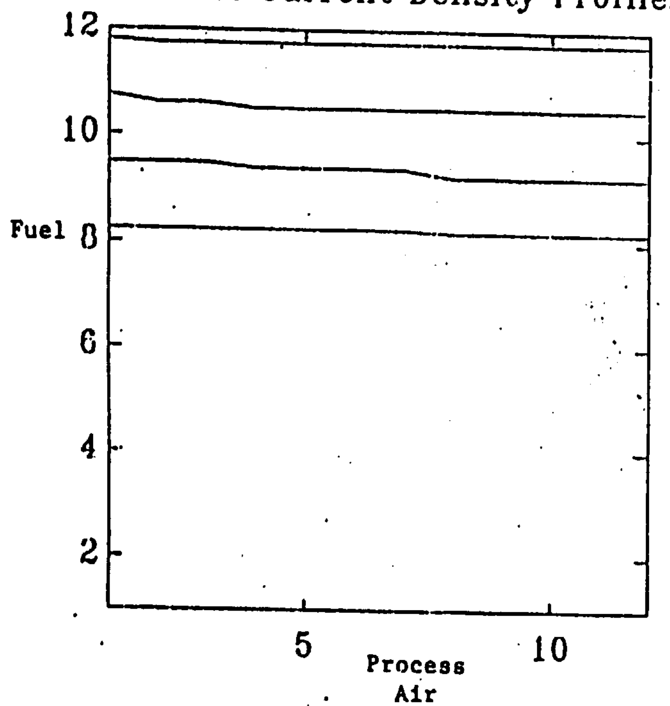
COOLING FLUID: WATER

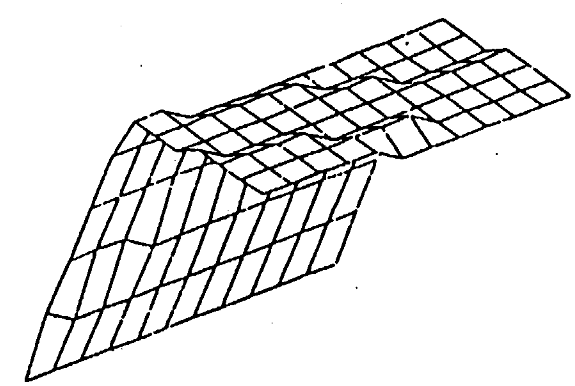
SHUT-DOWN PROCESS

TIME INTERVAL NO.11

TABLE D-11. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 11).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

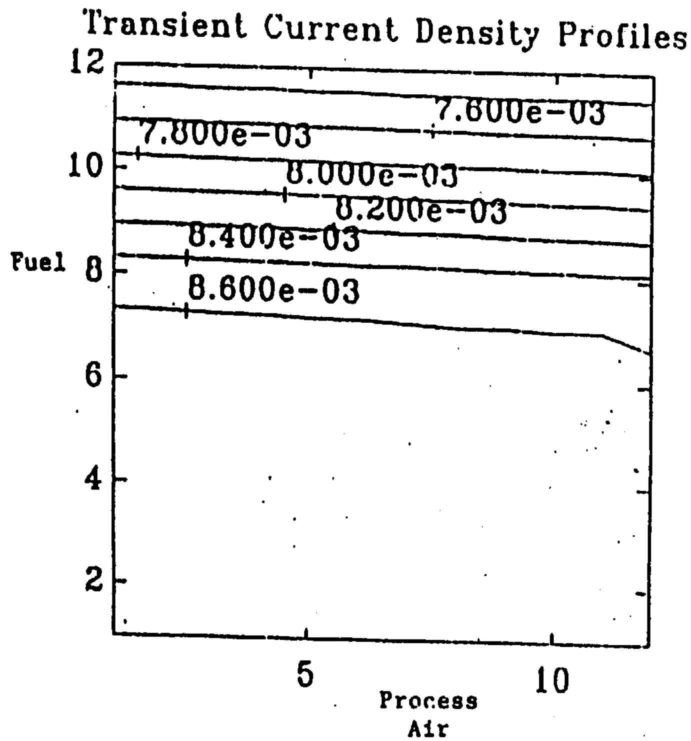
COOLING FLUID: WATER

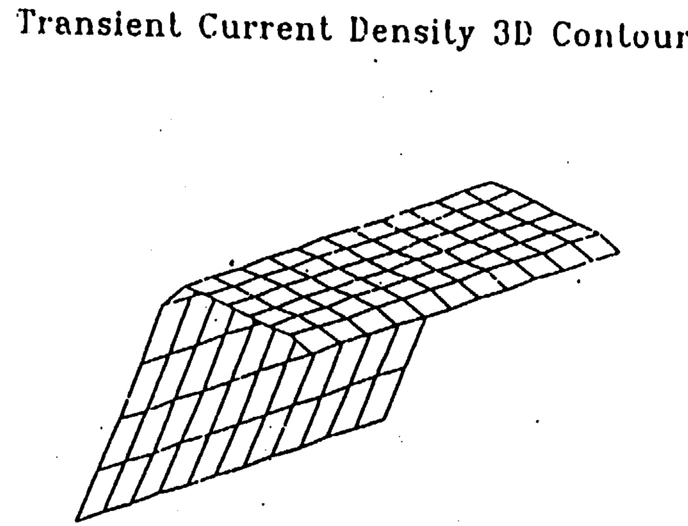
SHUT-DOWN PROCESS

TIME INTERVAL NO.12

TABLE D-12. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 KPa, Re = 1250, T.I. = 12).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=3500 KPa

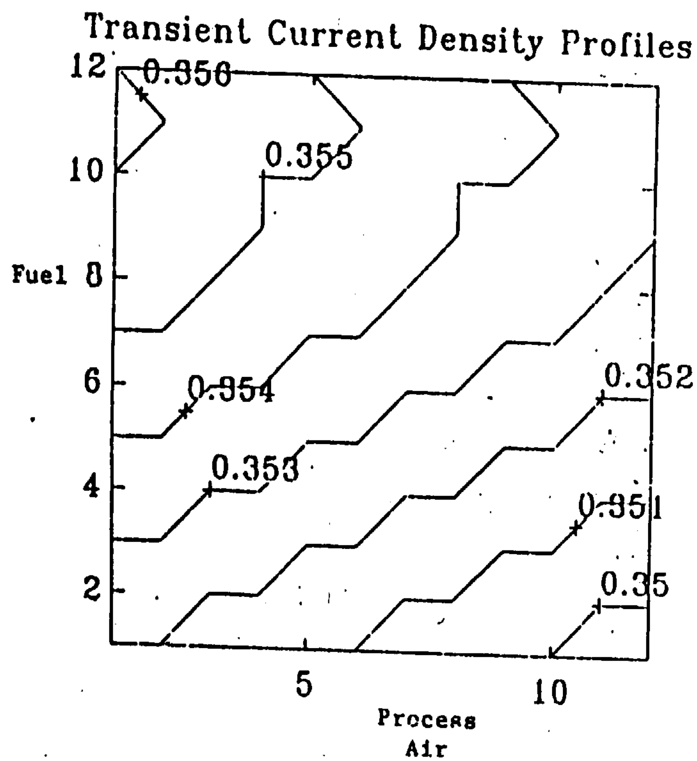
COOLING FLUID: WATER

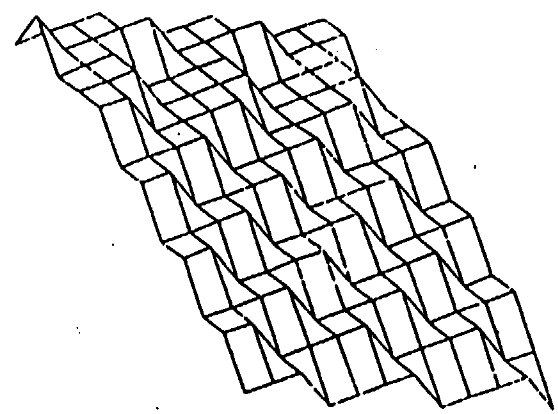
SHUT-DOWN PROCESS

TIME INTERVAL NO.13

TABLE D-13. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 3500 kPa, Re = 1250, T.I. = 13).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=0 KPa

COOLING FLUID: WATER

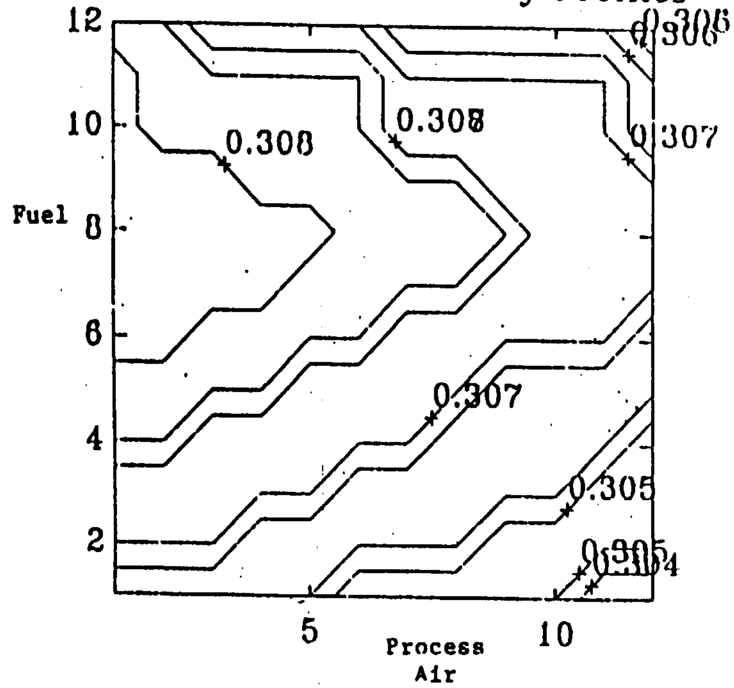
SHUT-DOWN PROCESS

TIME INTERVAL NO.1

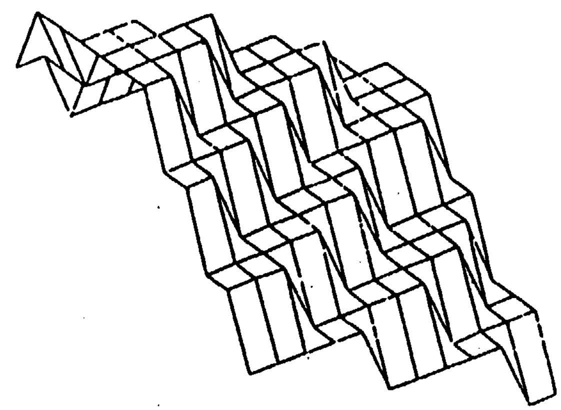
TABLE D-14. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 1).

## TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

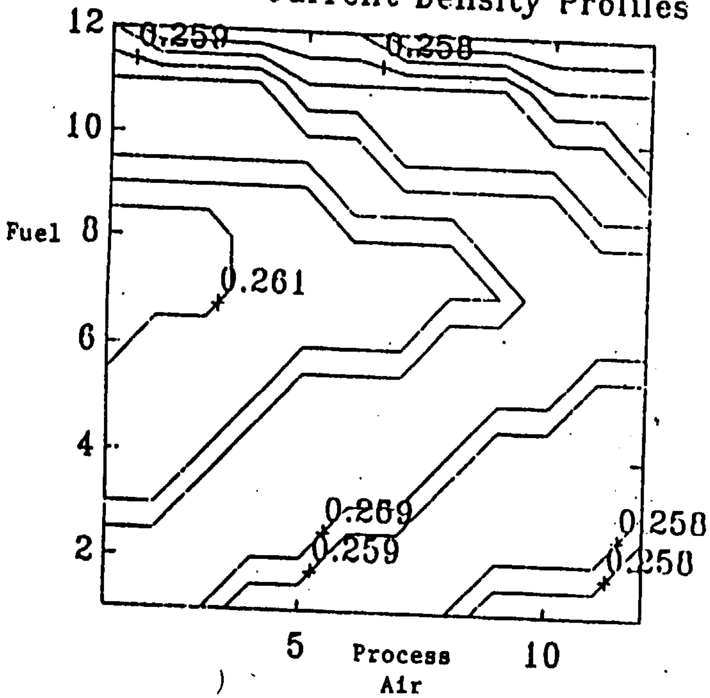
SHUT-DOWN PROCESS

TIME INTERVAL NO.2

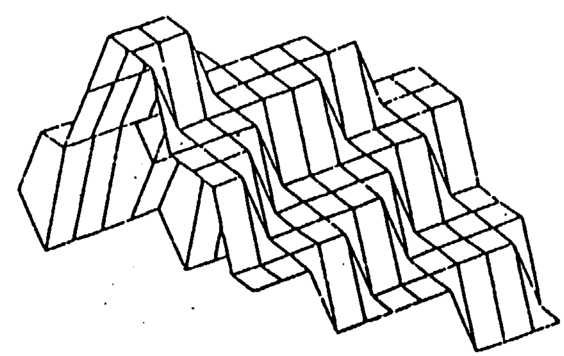
TABLE D-15. . Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 2.

# TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

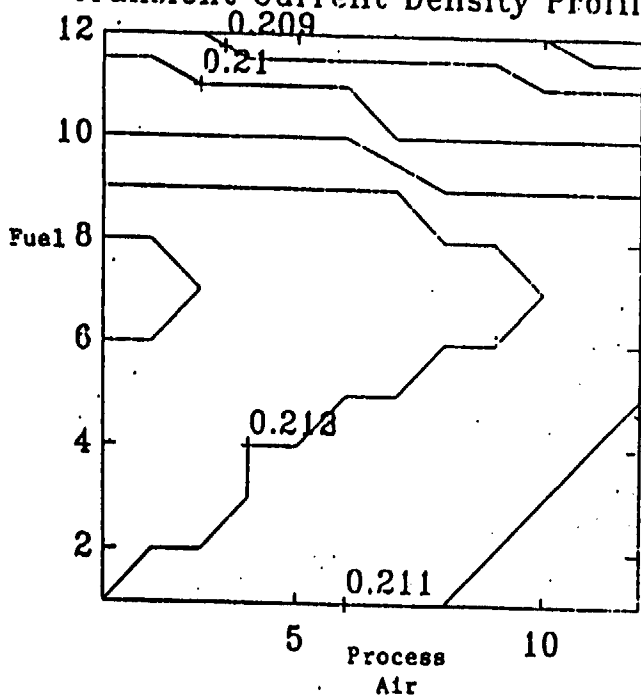
SHUT-DOWN PROCESS

TIME INTERVAL NO.3

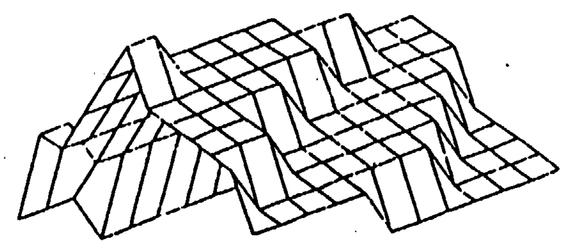
TABLE D-16. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 3).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

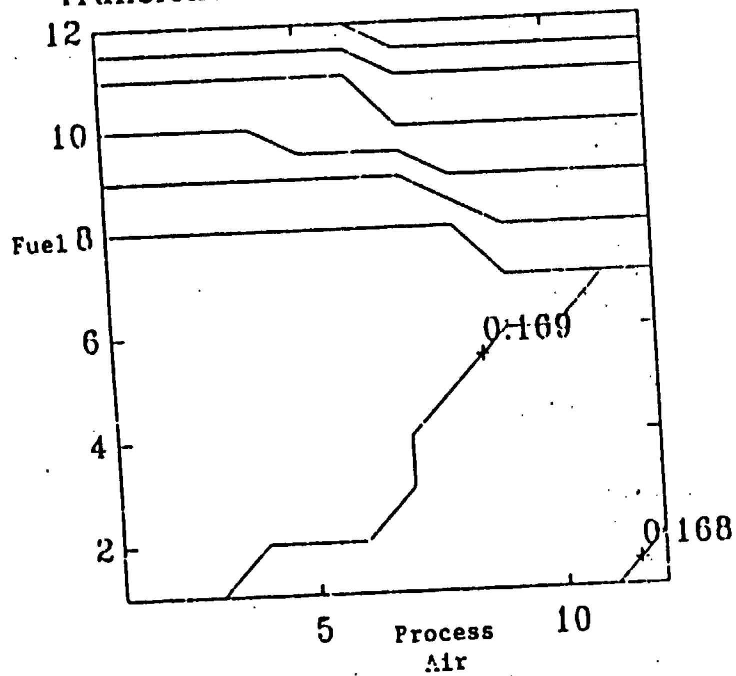
SHUT-DOWN PROCESS

TIME INTERVAL NO.4

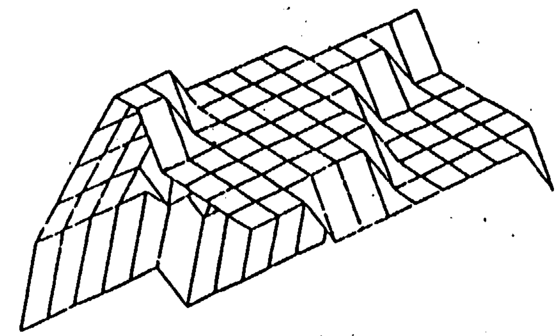
TABLE D-17. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 4).

# TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

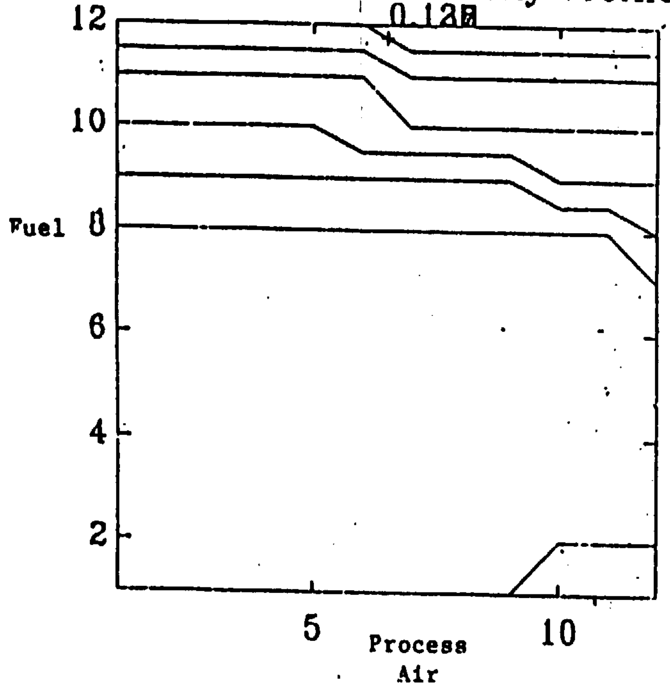
SHUT-DOWN PROCESS

TIME INTERVAL NO.5

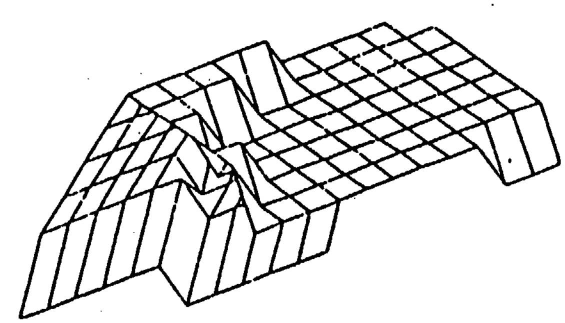
TABLED-18. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 5).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

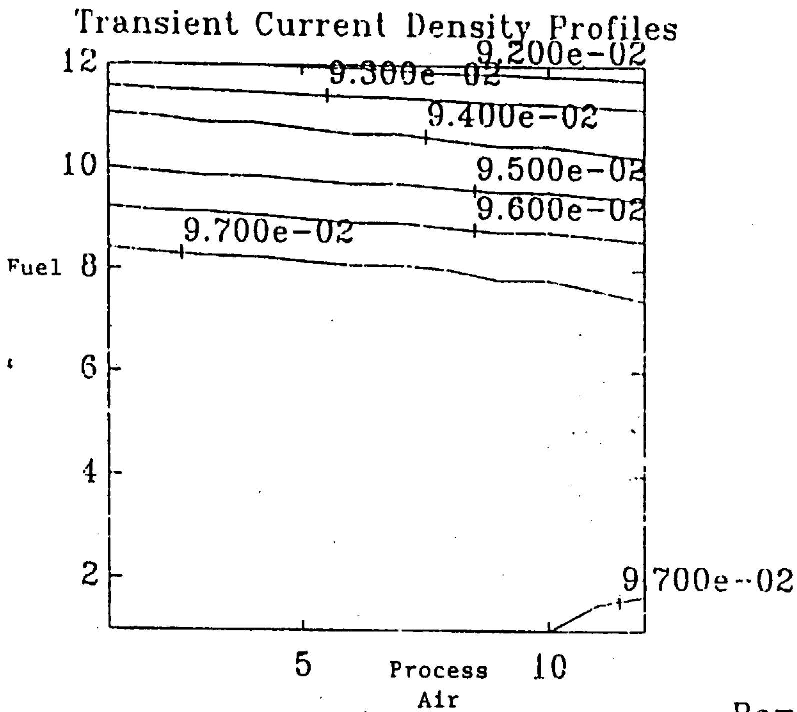
COOLING FLUID: WATER

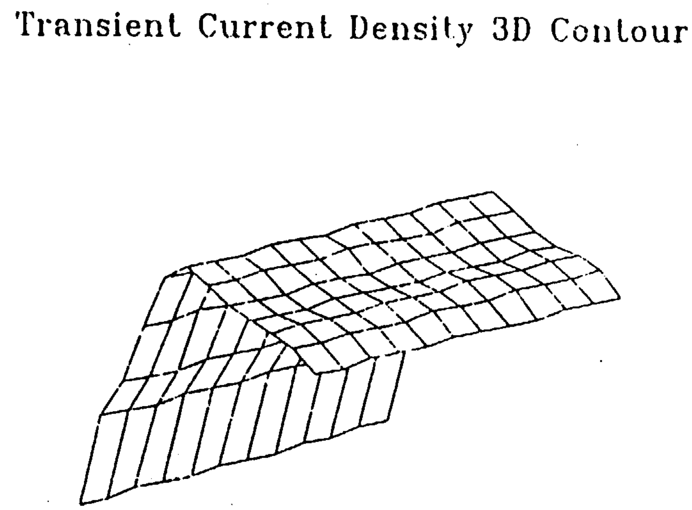
SHUT-DOWN PROCESS

TIME INTERVAL NO.6

TABLE D-19. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa Re = 1250, T.I. = 6).

# TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=0 KPa

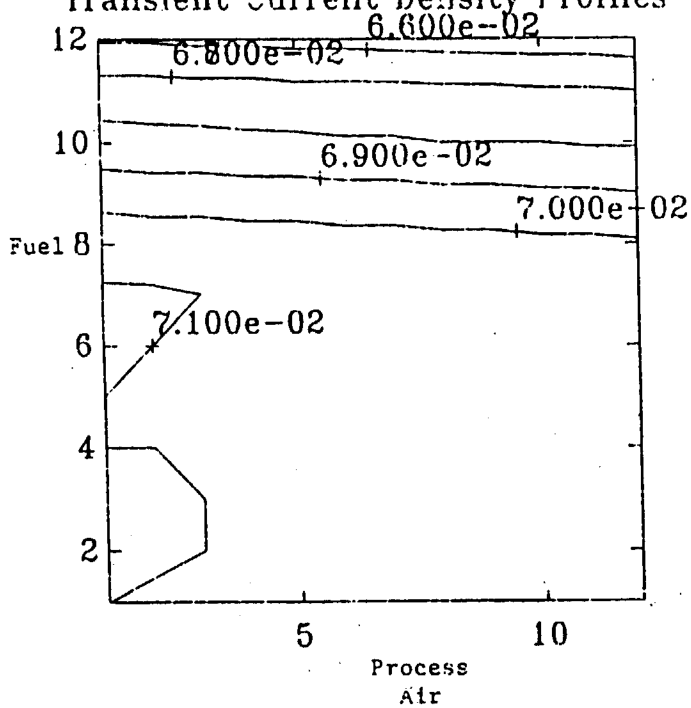
COOLING FLUID: WATER

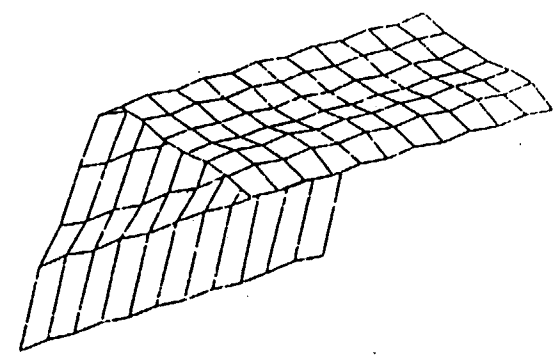
SHUT-DOWN PROCESS

TIME INTERVAL NO.7

TABLE D-20. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 7).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=1250,P=0 KPa

COOLING FLUID: WATER

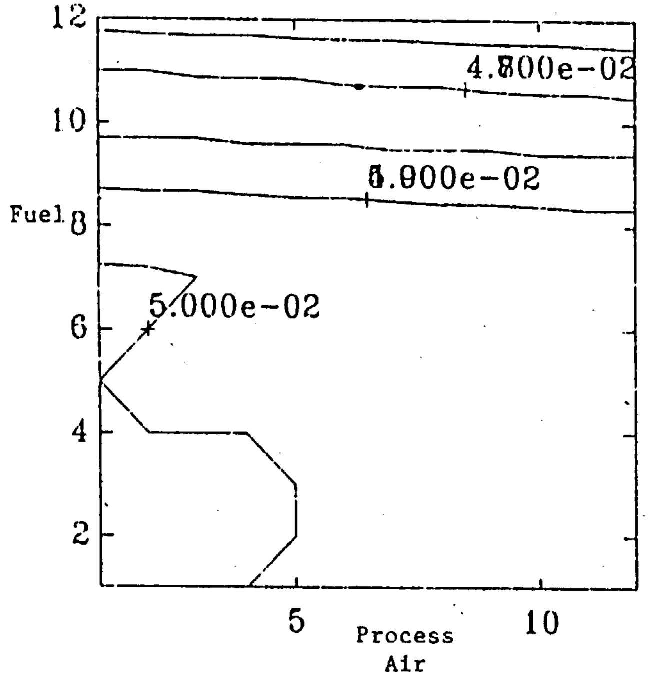
SHUT-DOWN PROCESS

TIME INTERVAL NO.8

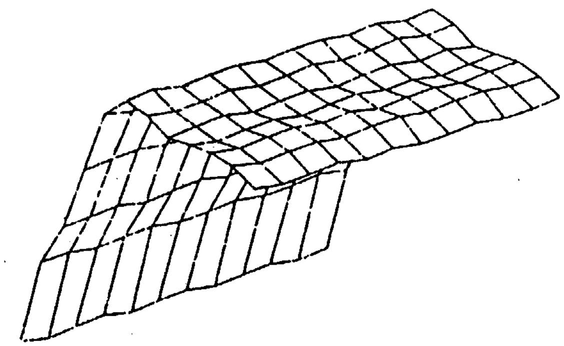
TABLE D-21. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 8).

# TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

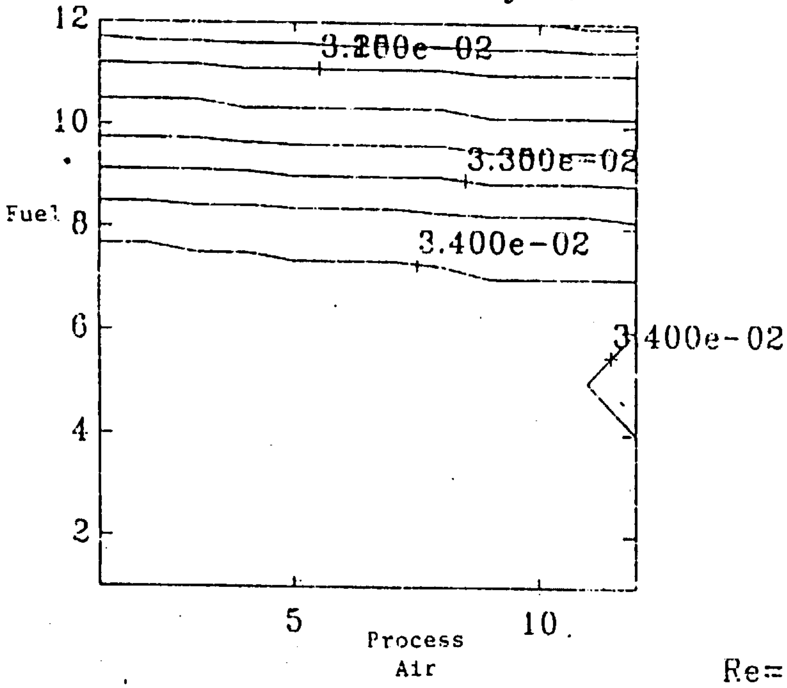
SHUT-DOWN PROCESS

TIME INTERVAL NO.9

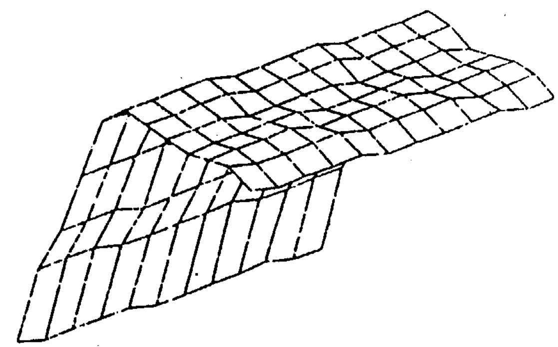
TABLE D-22. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 9).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

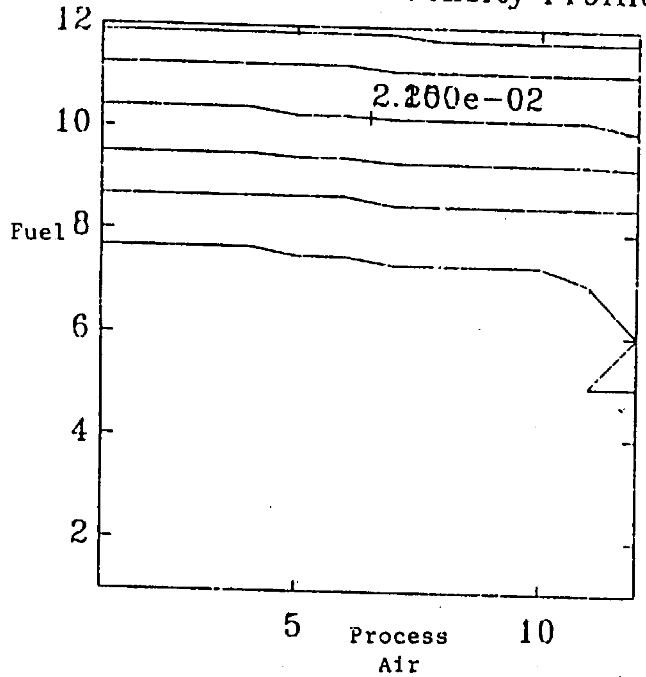
SHUT-DOWN PROCESS

TIME INTERVAL NO.10

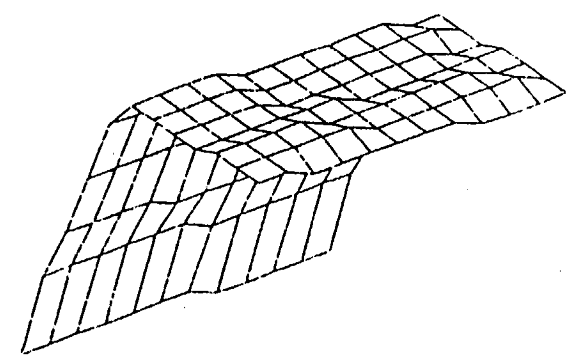
TABLE D-23. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 10).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

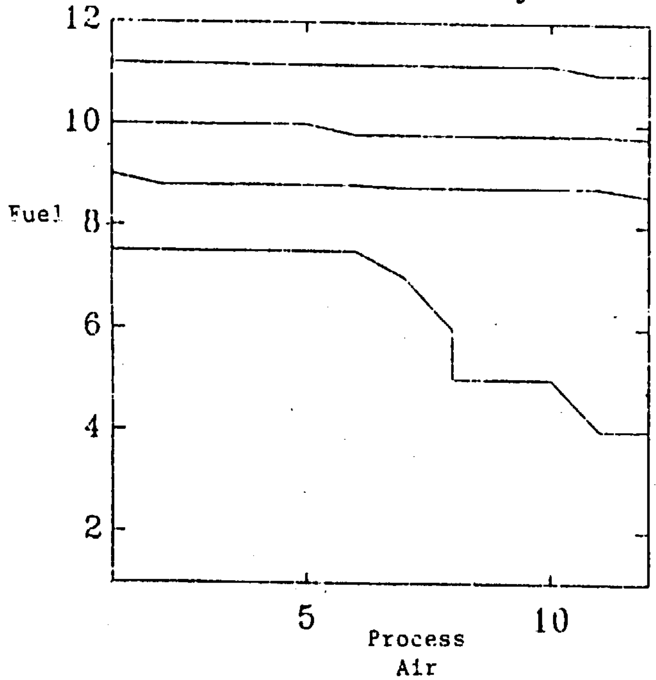
SHUT-DOWN PROCESS

TIME INTERVAL NO.11

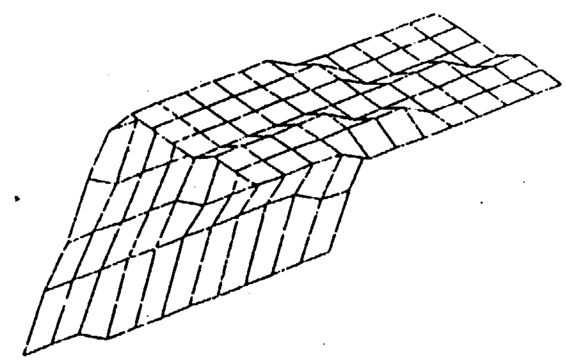
TABLE D-24. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 11).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

SHUT-DOWN PROCESS

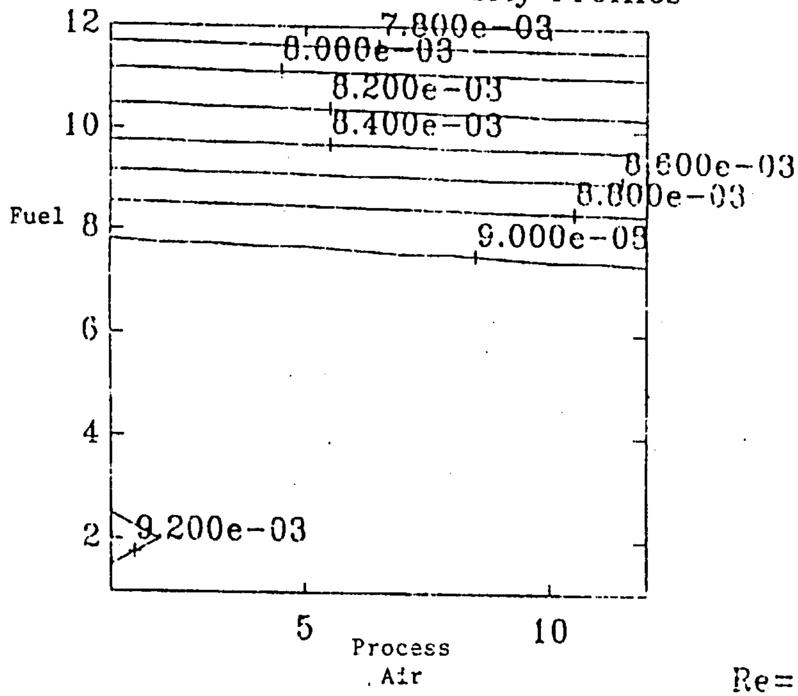
TIME INTERVAL NO.12

TABLE D-25. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 12).

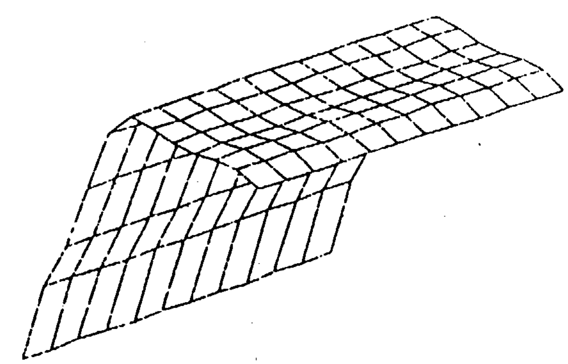
D-5.

## TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=1250,P=0 KPa

COOLING FLUID: WATER

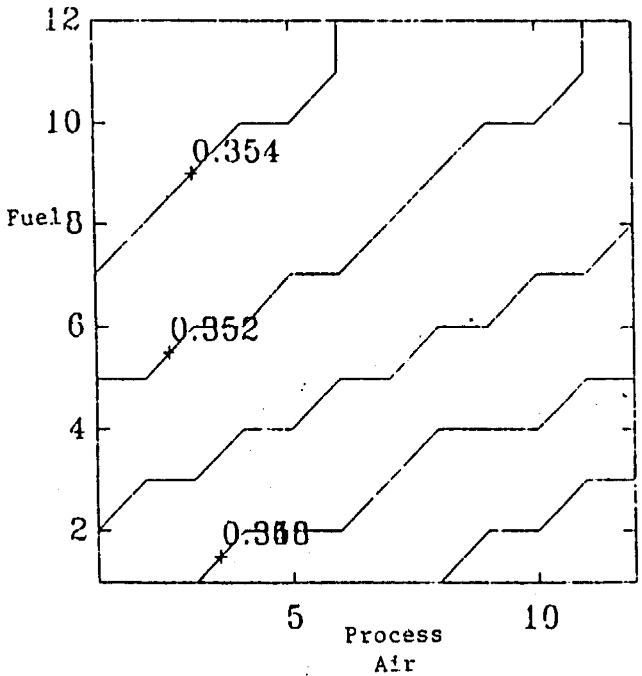
SHUT-DOWN PROCESS

TIME INTERVAL NO.13

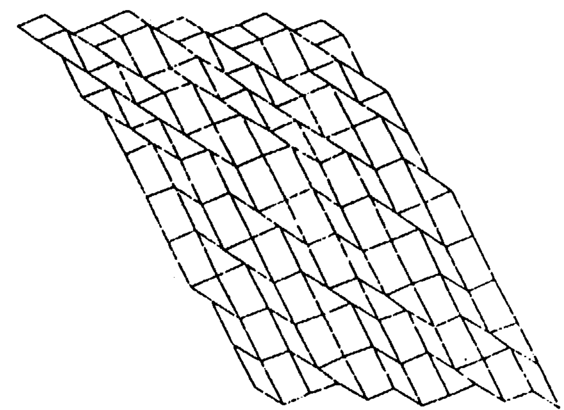
TABLE D-26. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 1250, T.I. = 13).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=6167,P=0 KPa

COOLING FLUID: WATER

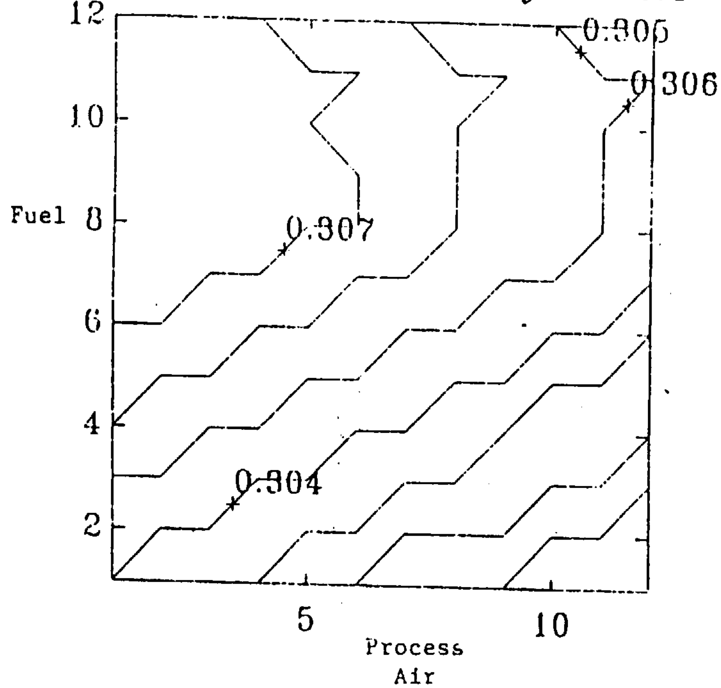
SHUT-DOWN PROCESS

TIME INTERVAL NO.1

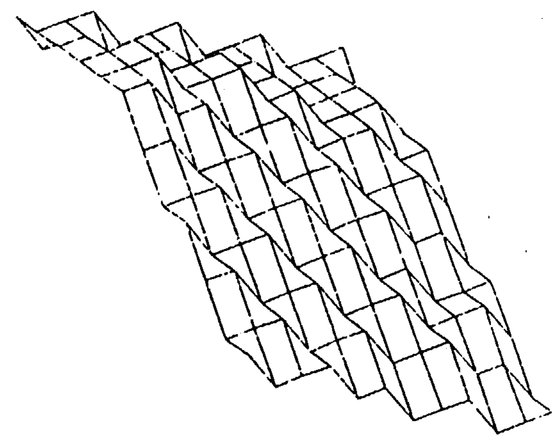
TABLE D-27. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 1).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=6167,P=0 KPa

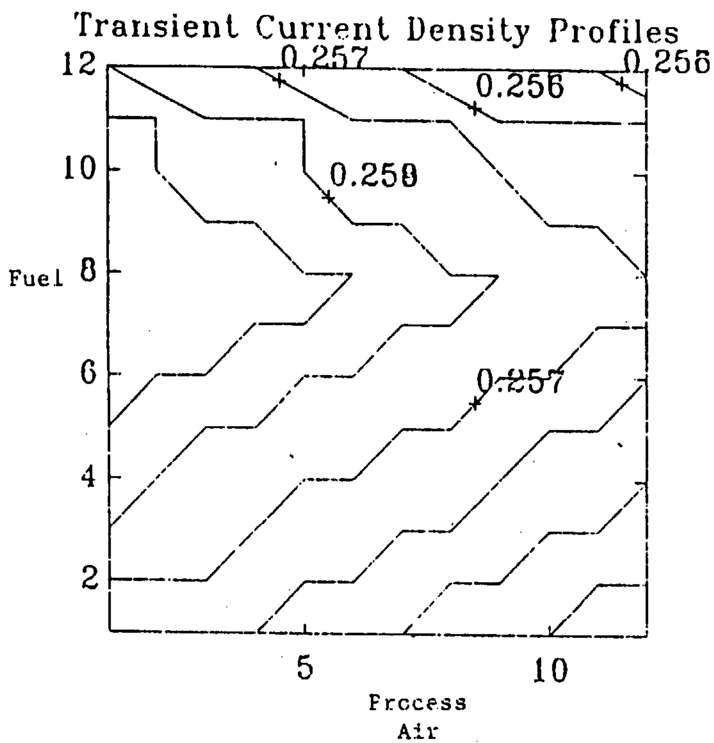
COOLING FLUID: WATER

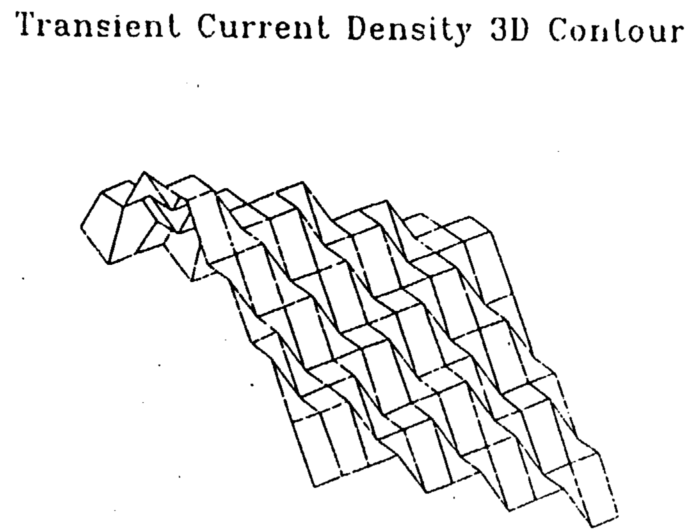
SHUT-DOWN PROCESS

TIME INTERVAL NO.2

TABLE D-28. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 2).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

COOLING FLUID: WATER

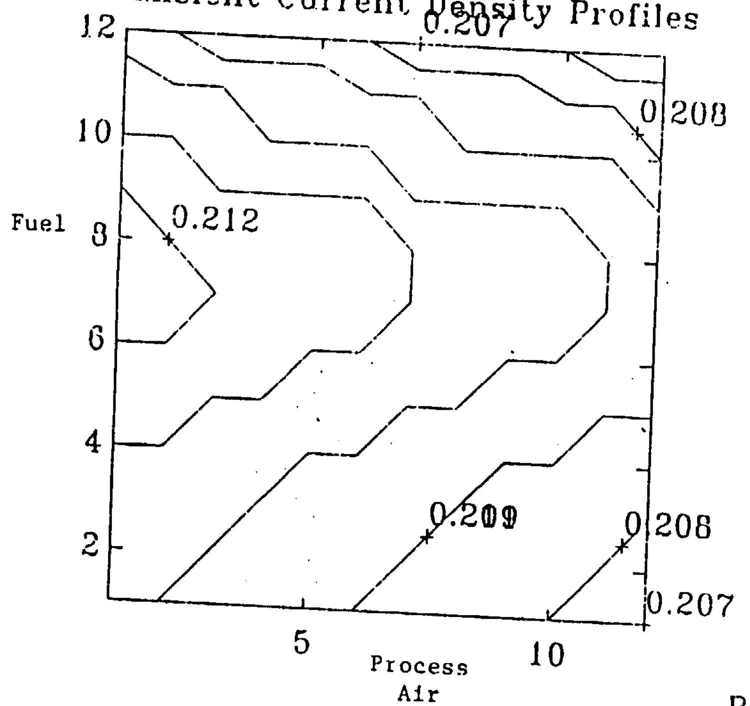
SHUT-DOWN PROCESS

TIME INTERVAL NO.3

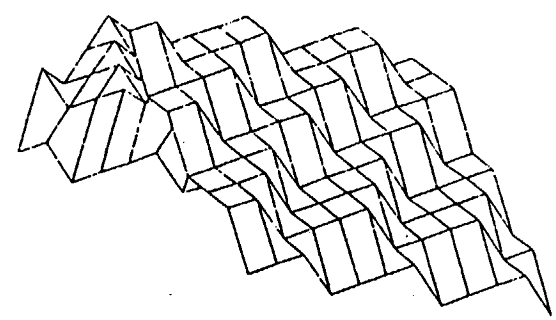
TABLE D-29. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 3).

# TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=6167,P=0 KPa

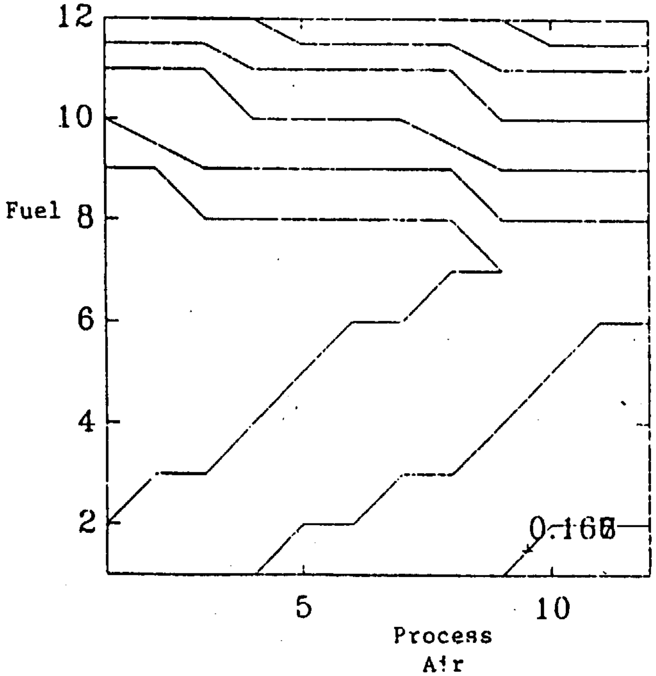
COOLING FLUID: WATER

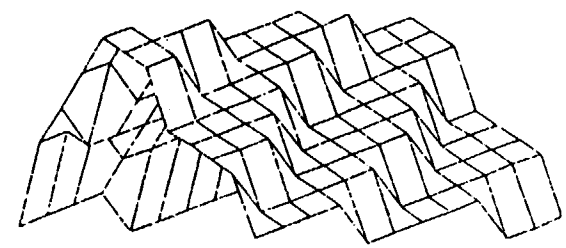
SHUT-DOWN PROCESS

TIME INTERVAL NO.4

TABLE D-30. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 4).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

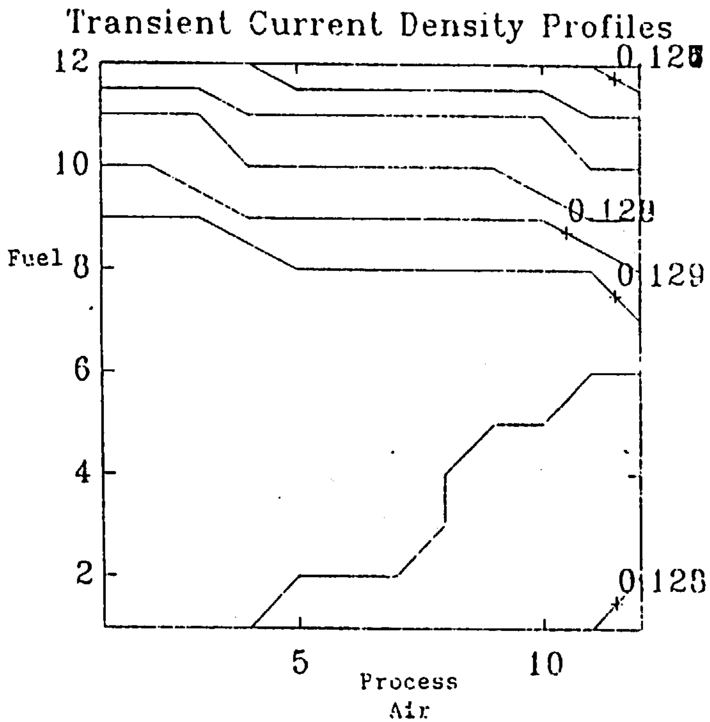
COOLING FLUID: WATER

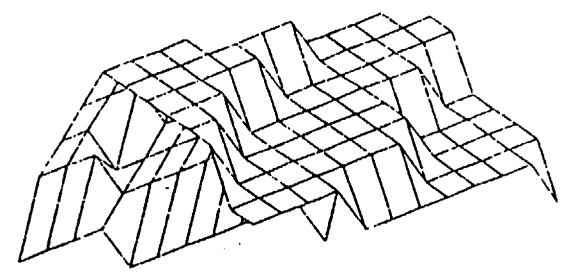
SHUT-DOWN PROCESS

TIME INTERVAL NO.5

TABLE D-31. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 5).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

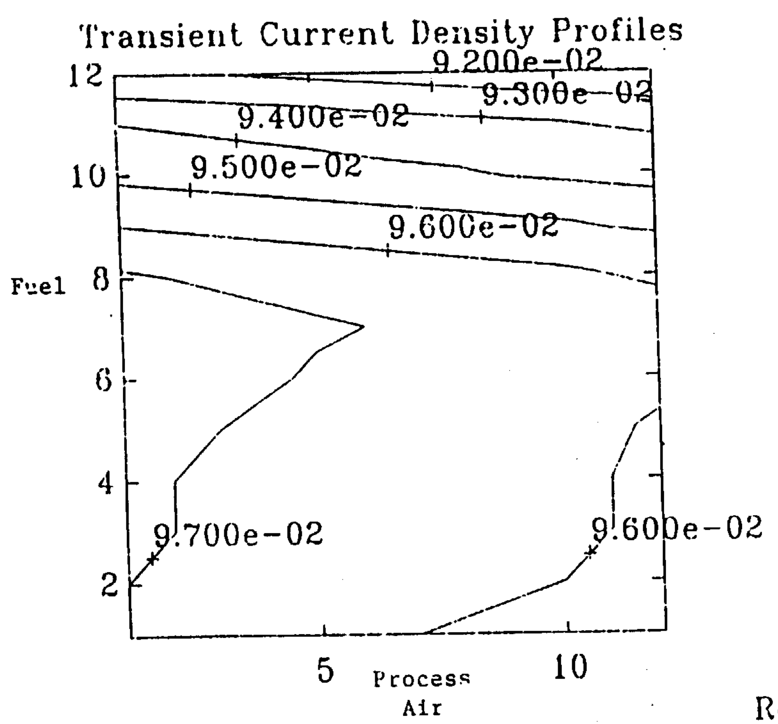
COOLING FLUID: WATER

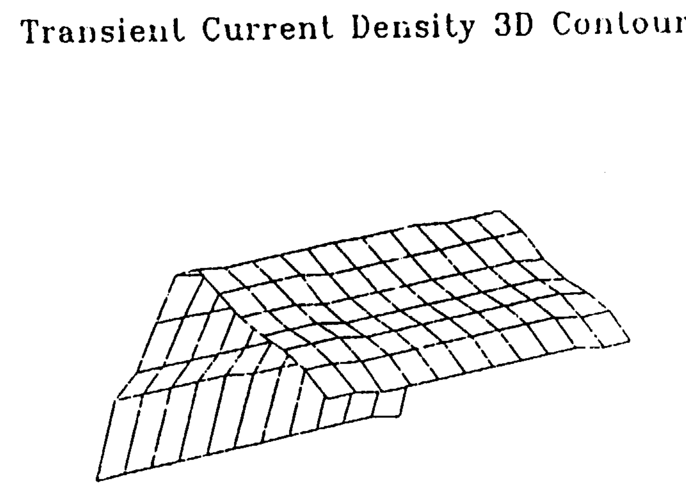
SHUT–DOWN PROCESS

TIME INTERVAL NO.6

TABLE D-32. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 6).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

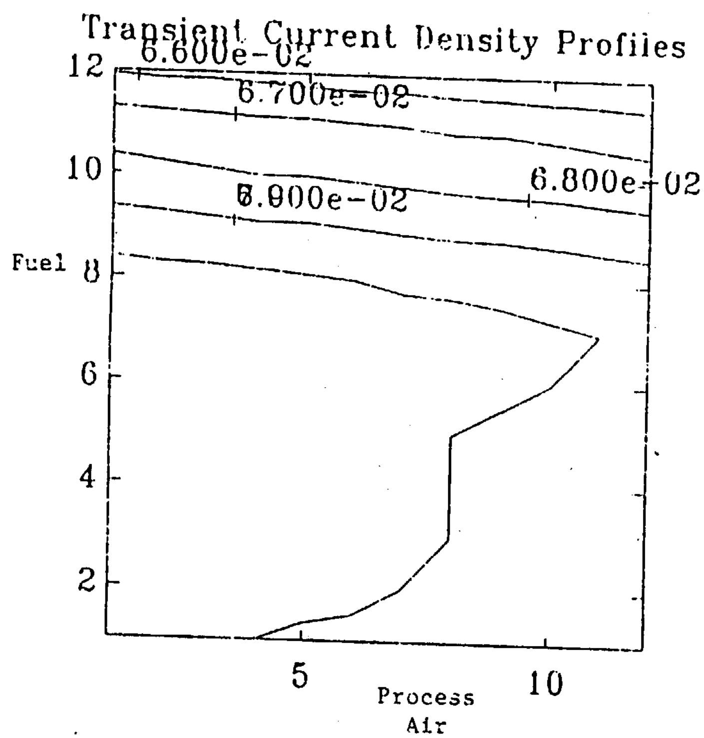
COOLING FLUID: WATER

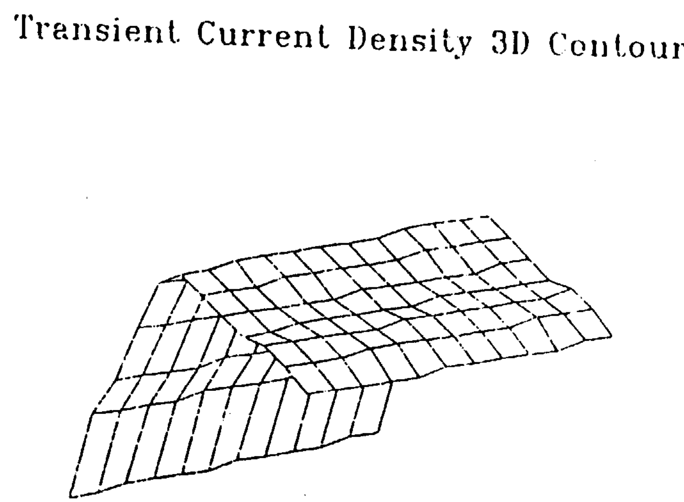
SHUT-DOWN PROCESS

TIME INTERVAL NO.7

TABLE D-33. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 7).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

COOLING FLUID: WATER

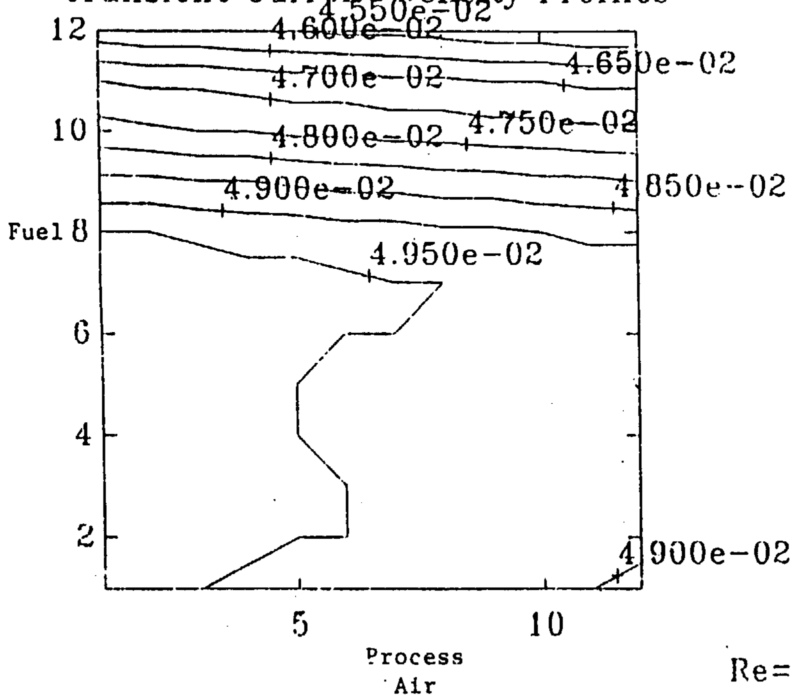
SHUT-DOWN PROCESS

TIME INTERVAL NO.8

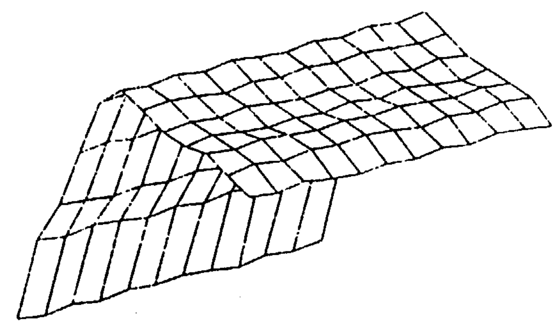
TABLE D-34. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 8).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=6167,P=0 KPa

COOLING FLUID: WATER

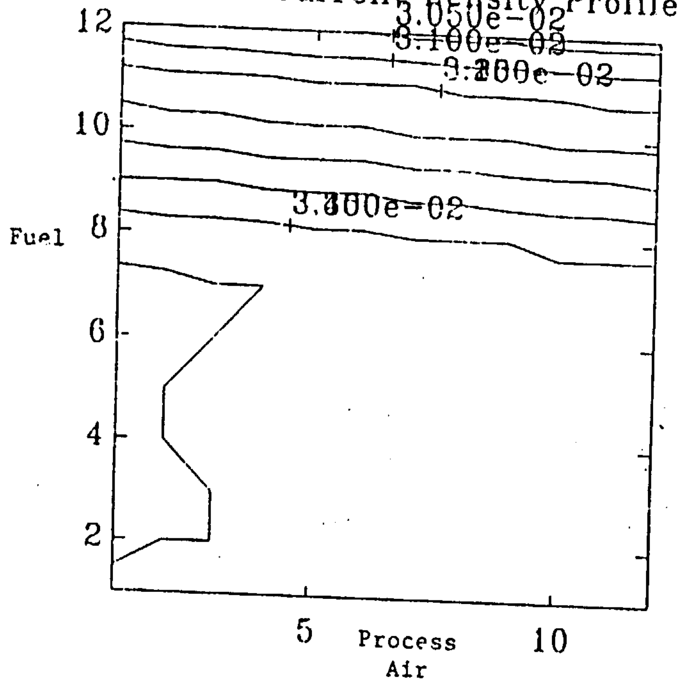
SHUT-DOWN PROCESS

TIME INTERVAL NO.9

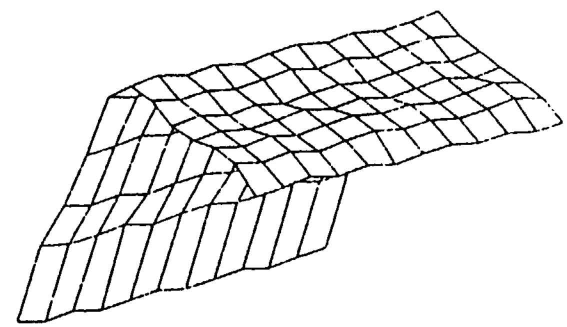
TABLE D-35. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 9).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=6167,P=0 KPa

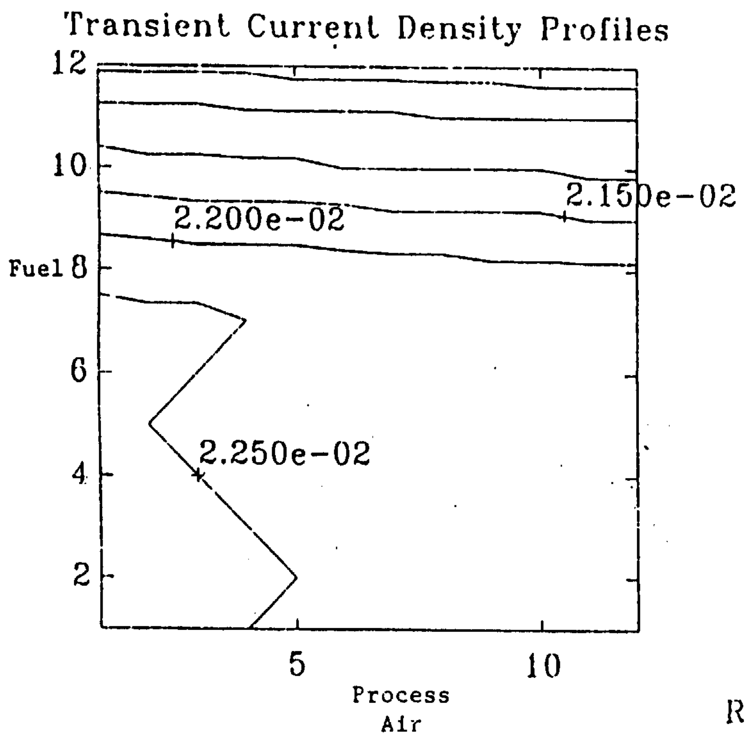
COOLING FLUID: WATER

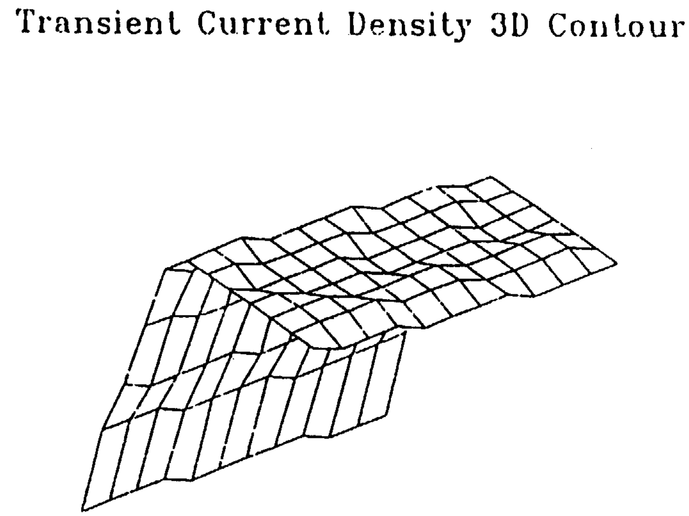
SHUT-DOWN PROCESS

TIME INTERVAL NO.10

TABLE D-36. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0, KPa, Re = 6167, T.I. = 10).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

COOLING FLUID: WATER

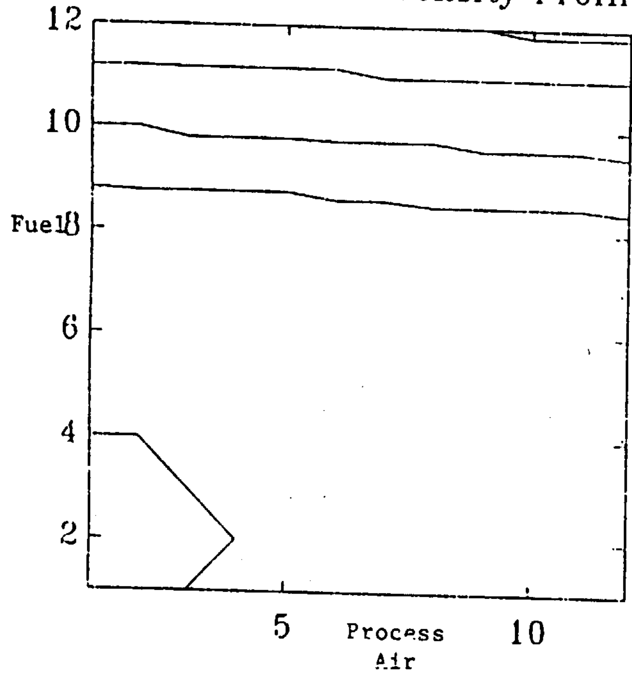
SHUT-DOWN PROCESS

TIME INTERVAL NO.11

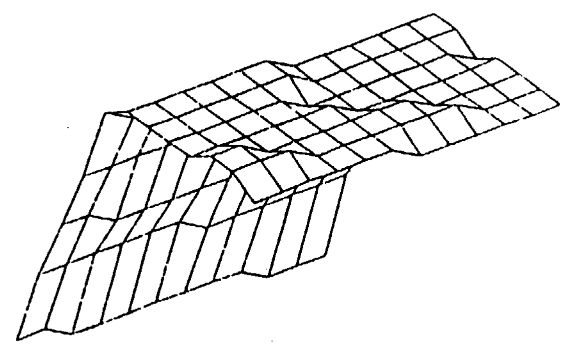
TABLE D-37. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 11).

TRANSIENT CURRENT DENSITY DISTRIBUTION

Transient Current Density Profiles




Transient Current Density 3D Contour



Re=6167,P=0 KPa

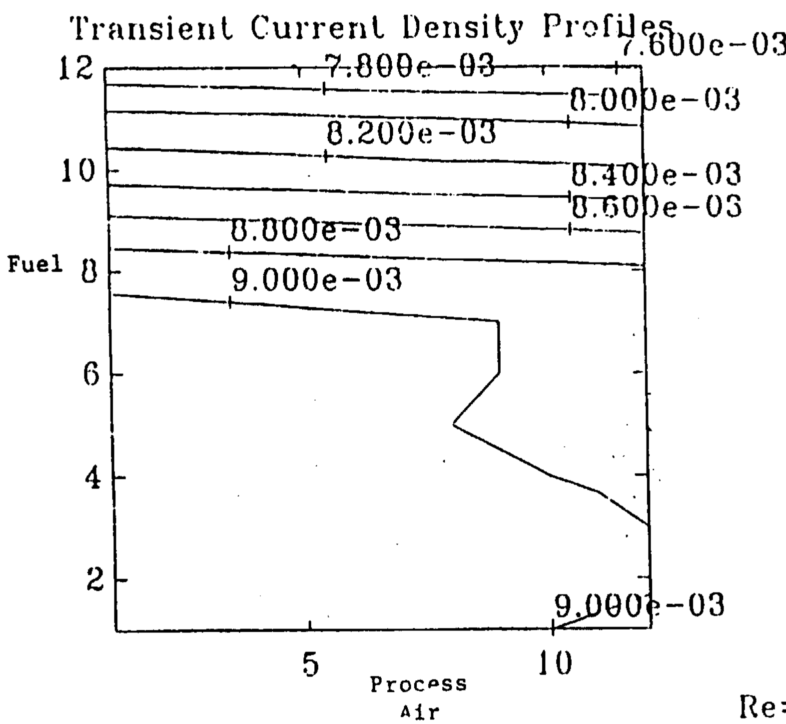
COOLING FLUID: WATER

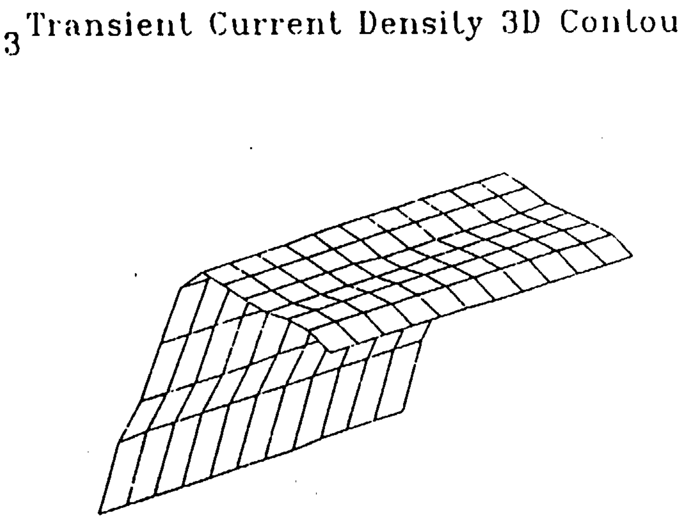
SHUT-DOWN PROCESS

TIME INTERVAL NO.12

TABLE D-38. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 12).

TRANSIENT CURRENT DENSITY DISTRIBUTION




Re=6167,P=0 KPa

COOLING FLUID: WATER

SHUT-DOWN PROCESS

TIME INTERVAL NO.13

TABLE D-39. Transient Current Density Distribution During a Shut-Down Process (Water Coolant, P = 0 KPa, Re = 6167, T.I. = 13).

# APPENDIX E

## EXPERIMENTAL ($T_w$) TEMPERATURES

TABLE (E-1) WATER COOLANT AT (t=120 MIN)

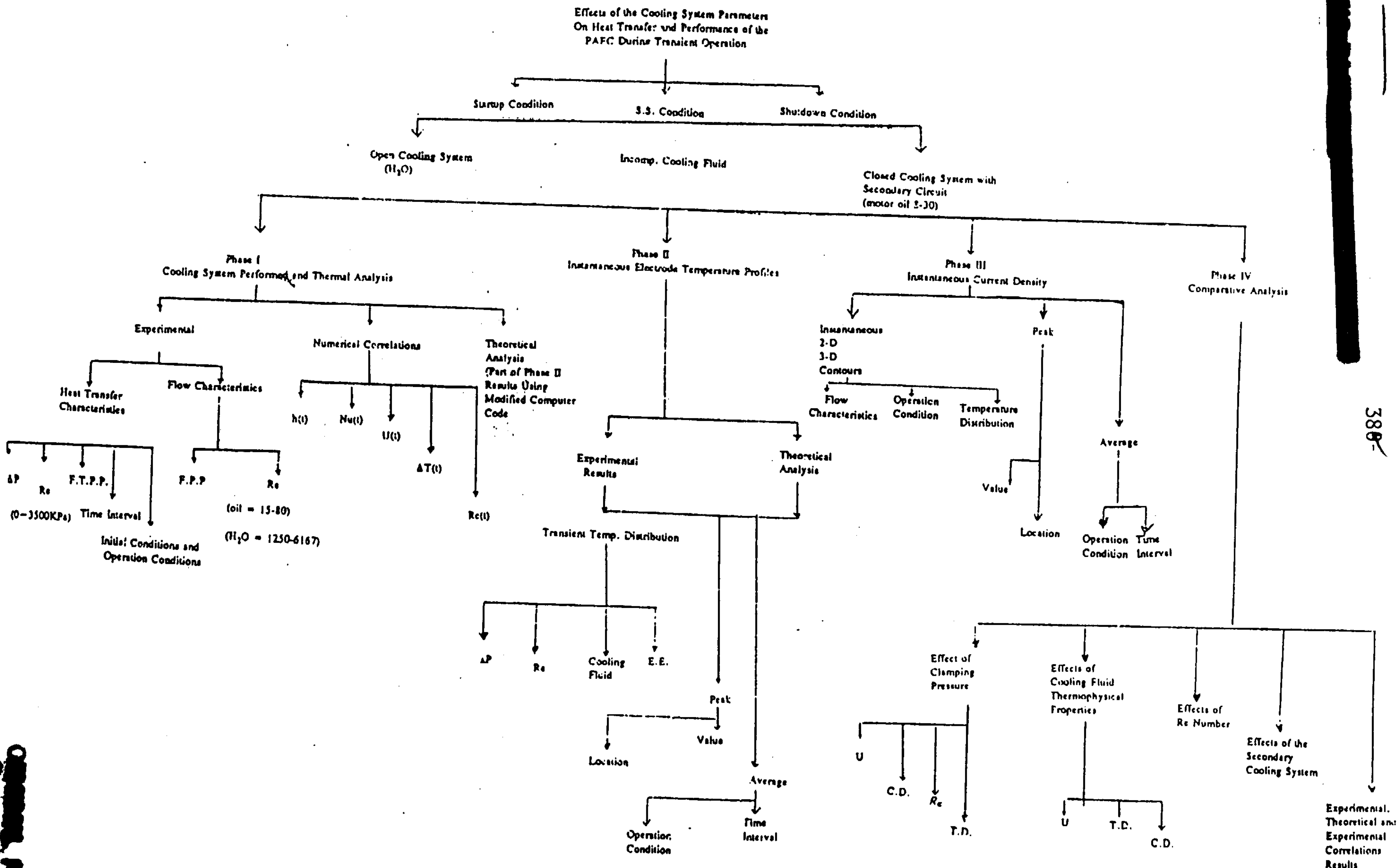
TABLE (E-2) OIL COOLANT AT (t=120 MIN)

WATER COOLANT ($t = 120$ min)

| OPERATION CONDITION | $T_3$ C° | $T_2$ C° | $T_x$ C° |
|---|---|---|---|
| Re = 1250<br>E.E. = 3000 $W/m^2$<br>P = 0 KPa | 92.11 | 90.46 | 88.71 |
| Re = 3321<br>E.E. = 3000 $W/m_2$<br>P = 0 KPa | 89.98 | 87.61 | 84.91 |
| Re = 6167<br>E.E. = 3000 $W/m_2$<br>P = 0 KPa | 82.31 | 79.11 | 76.91 |
| Re = 1250<br>E.E. = 3000 $W/m_2$<br>P = 1400 KPa | 97.25 | 94.51 | 91.01 |
| Re = 3321<br>E.E. = 3000 $W/m_2$<br>P = 14 KPa | 88.25 | 85.71 | 82.71 |
| Re = 6167<br>E.E. = 3000 $W/m_2$<br>P = 1400 KPa | 84.11 | 80.44 | 78.91 |
| Re = 1250<br>E.E. = 3000 $W/m_2$<br>P = 2800 KPa | 97.01 | 94.98 | 92.12 |
| Re = 3321<br>E.E. = 3000 $W/m_2$<br>P = 2800 KPa | 88.24 | 86.98 | 83.91 |
| Re = 6167<br>E.E. = 3000 $W/m_2$<br>P = 2800 KPa | 86.91 | 89.11 | 81.91 |
| Re = 1250<br>E.E. = 3000 $W/m_2$<br>P = 3500 KPa | 83.87 | 81.91 | 78.98 |
| Re = 3321<br>E.E. = 3000 $W/M_2$<br>P = 3500 KPa | 73.01 | 71.81 | 68.01 |
| Re = 6167<br>E.E. = 3000 $W/m_2$<br>P = 3500 KPa | 73.02 | 70.10 | 67.23 |

OIL COOLANT (t = 120 min)

| OPERATION CONDITION | $T_3$ C° | $T_2$ C° | $T_1$ C° |
|---|---|---|---|
| Re = 15<br>E.E. = 3000 W/$m_2$<br>P = 0 KPa | 129.01 | 128.77 | 126.99 |
| Re = 43<br>E.E. = 3000 W/$m_2$<br>P = 0 KPa | 122.04 | 122.10 | 120.9 |
| Re = 80<br>E.E. = 3000 W/$m_2$<br>P = 0 KPa | 119.81 | 118.34 | 117.01 |
| Re = 15<br>E.E. = 3000 W/$m_2$<br>P = 1400 KPa | 186.10 | 184.71 | 183.16 |
| Re = 43<br>E.E. = 3000 W/$m_2$<br>P = 1400 KPa | 121.05 | 119.87 | 118.1 |
| Re = 80<br>E.E. = 3000 W/$m_2$<br>P = 1400 KPa | 116.13 | 114.81 | 113.71 |
| Re = 15<br>E.E. = 3000 W/$m_2$<br>P = 2800 KPa | 168.33 | 165.87 | 162.71 |
| Re = 43<br>E.E. = 3000 W/$m_2$<br>P = 2800 KPa | 141.01 | 139.89 | 138.00 |
| Re = 80<br>E.E. = 3000 W/$m_2$<br>P = 3500 KPa | 113.01 | 111.82 | 108.11 |
| Re = 15<br>E.E. = 3000 W/$m_2$<br>P = 3500 KPa | 113.01 | 111.87 | 108.11 |
| Re = 43<br>E.E. = 3000 W/$m_2$<br>P = 3500 KPa | 136.1 | 134.89 | 131.98 |
| Re = 80<br>E.E. = 3000 W/$m_2$<br>P = 3500 KPa | 104.07 | 102.11 | 99.89 |


Effects of the Cooling System Parameters
On Heat Transfer and Performance of the
PAFC During Transient Operation
Startup Condition
S.S. Condition
Shutdown Condition
Open Cooling System
($H_2O$)
Incomp. Cooling Fluid
Closed Cooling System with
Secondary Circuit
(motor oil 5-30)
Phase I
Cooling System Performed and Thermal Analysis
Phase II
Instantaneous Electrode Temperature Profiles
Phase III
Instantaneous Current Density
Phase IV
Comparative Analysis
Experimental
Numerical Correlations
Theoretical
Analysis
(Part of Phase II
Results Using
Modified Computer
Code
Heat Transfer
Characteristics
Flow Characteristics
ΔP
Re
F.T.P.P.
Time Interval
(0–3500KPa)
Initial Conditions and
Operation Conditions
F.P.P
Re
(oil = 15-80)
($H_2O$ = 1250-6167)
h(t)
Nu(t)
U(t)
ΔT(t)
Re(t)
Experimental
Results
Theoretical
Analysis
Transient Temp. Distribution
ΔP
Re
Cooling
Fluid
E.E.
Peak
Value
Location
Average
Operation
Condition
Time
Interval
Instantaneous
2-D
3-D
Contours
Flow
Characteristics
Operation
Condition
Temperature
Distribution
Peak
Value
Location
Average
Operation
Condition
Time
Interval
Effect of
Clamping
Pressure
U
C.D.
Re
T.D.
Effects of
Cooling Fluid
Thermophysical
Properties
U
T.D.
C.D.
Effects of
Re Number
Effects of the
Secondary
Cooling System
Experimental,
Theoretical and
Experimental
Correlations
Results